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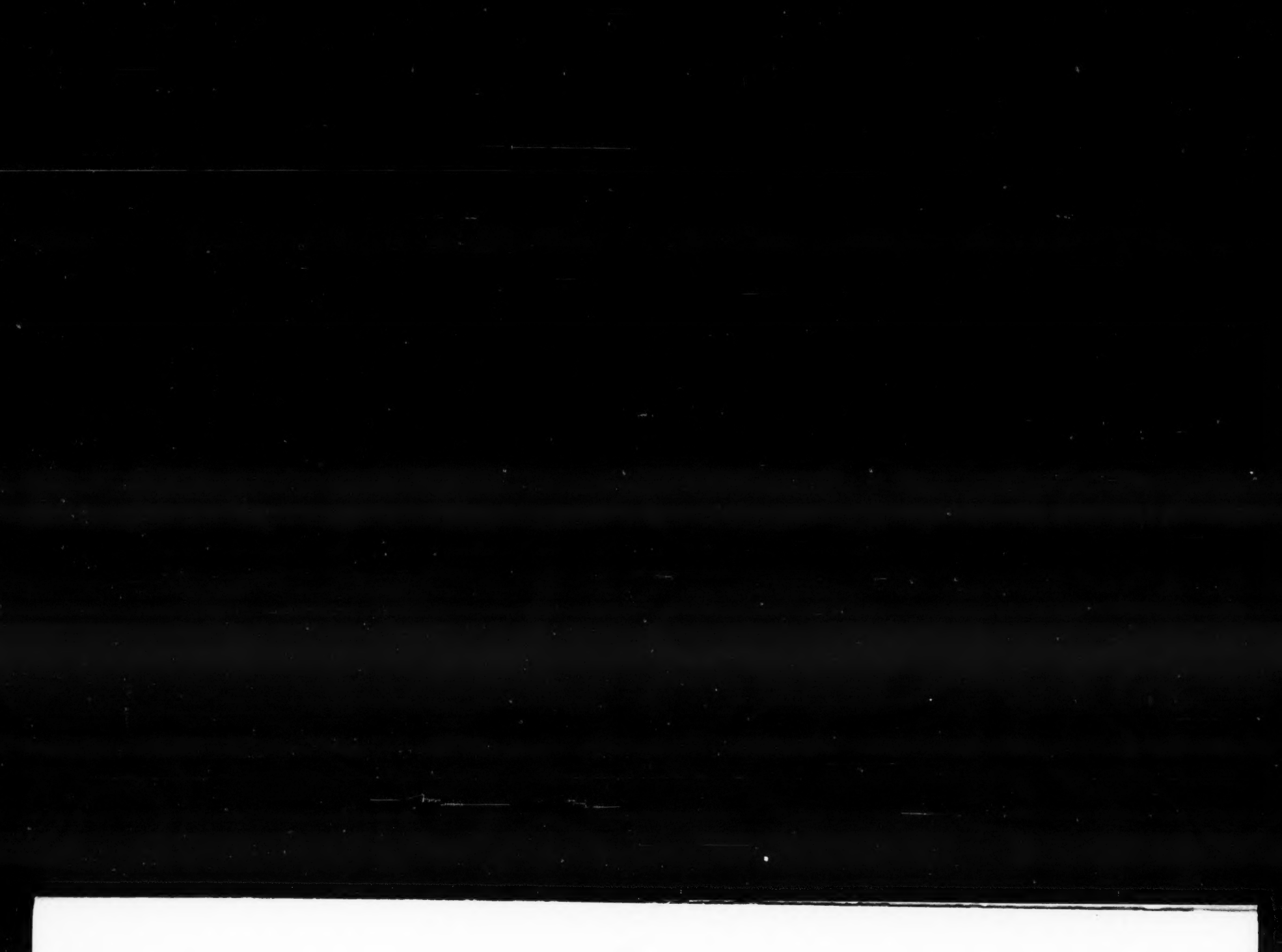

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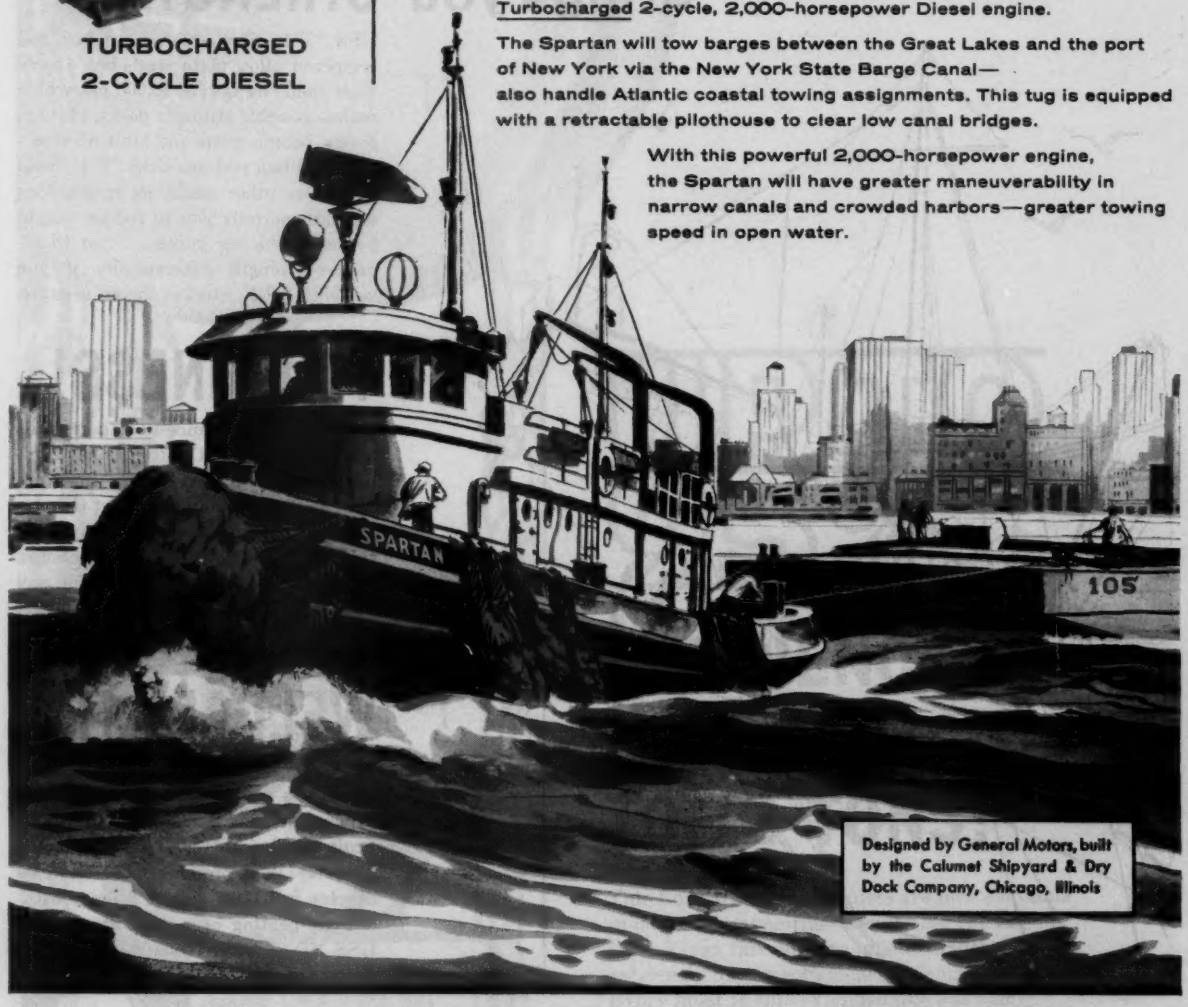

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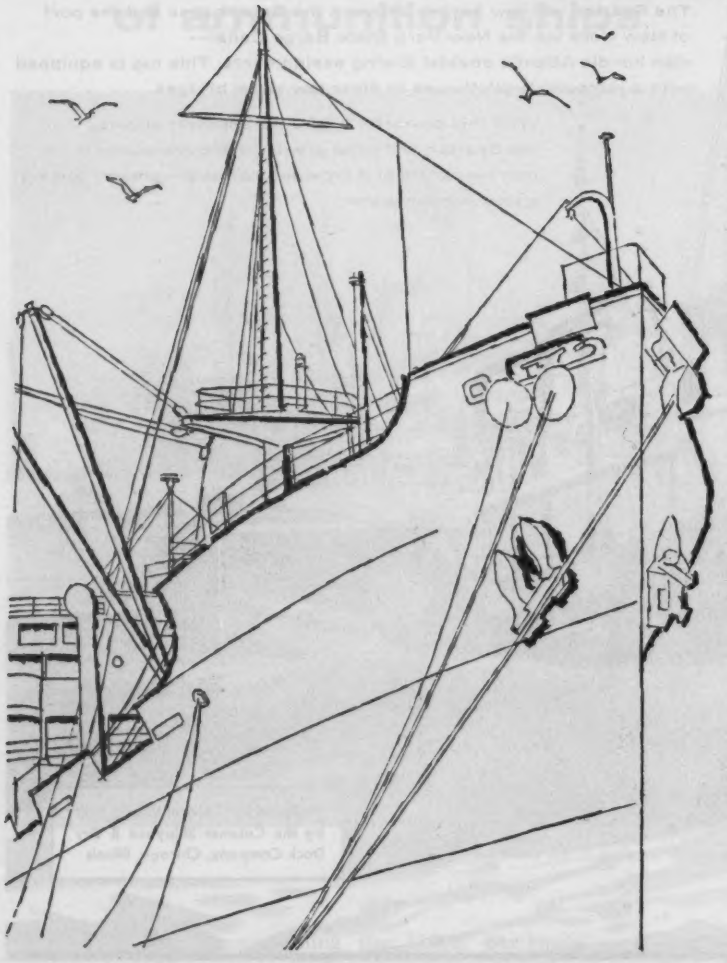

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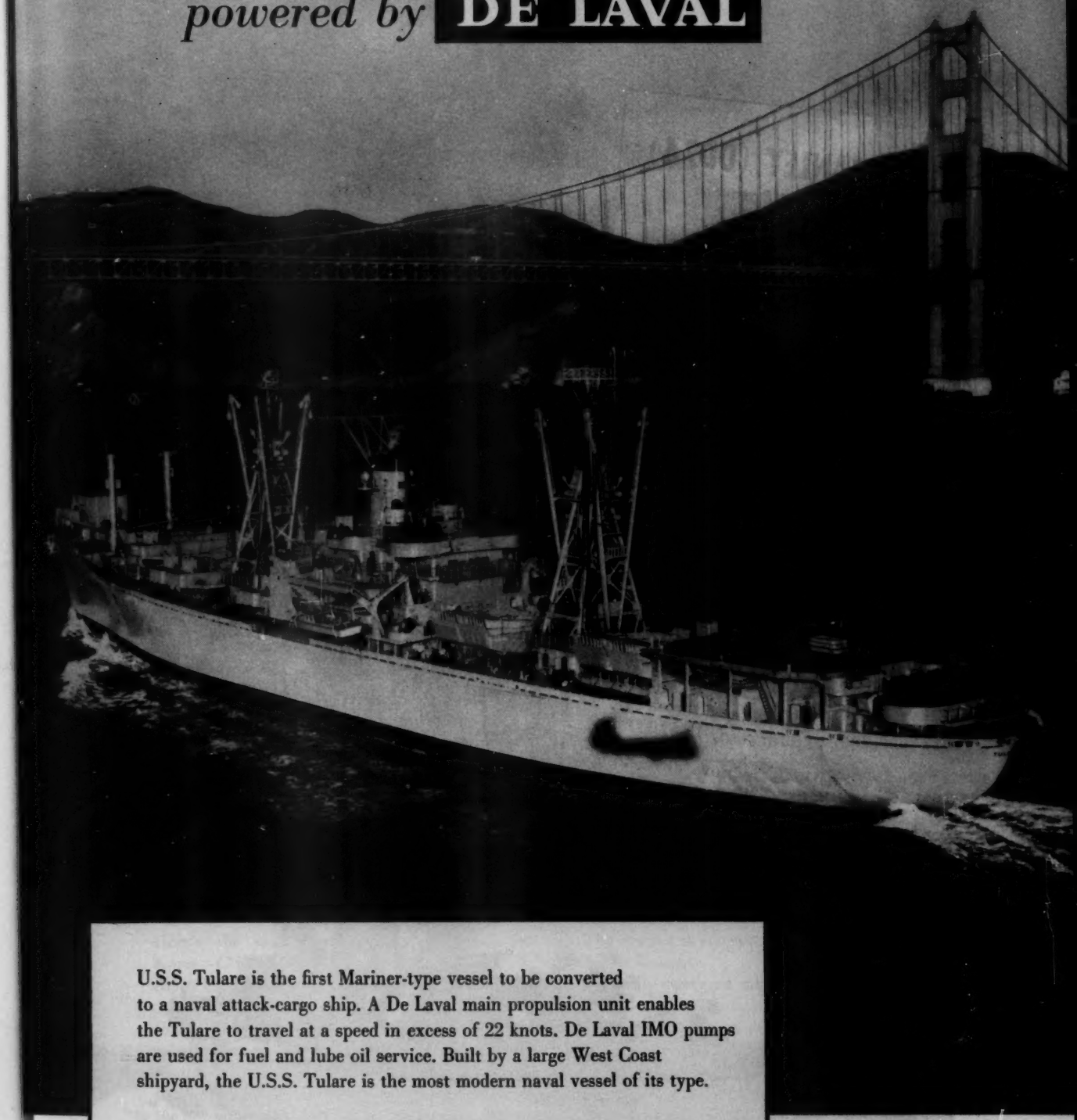

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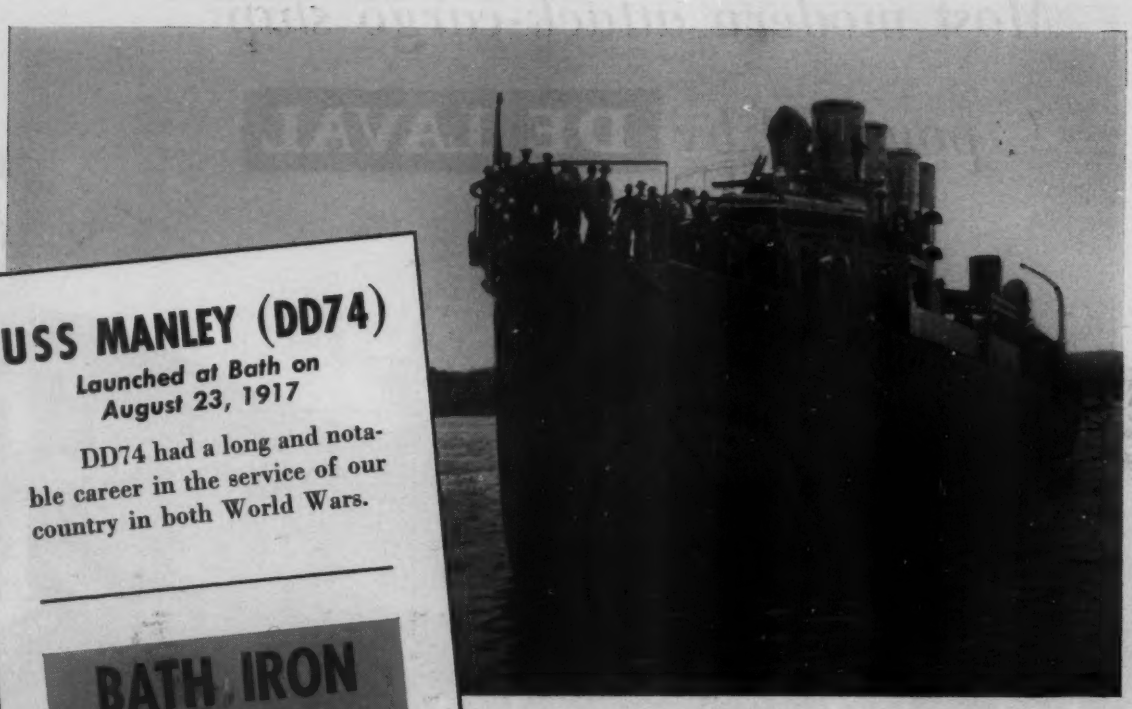

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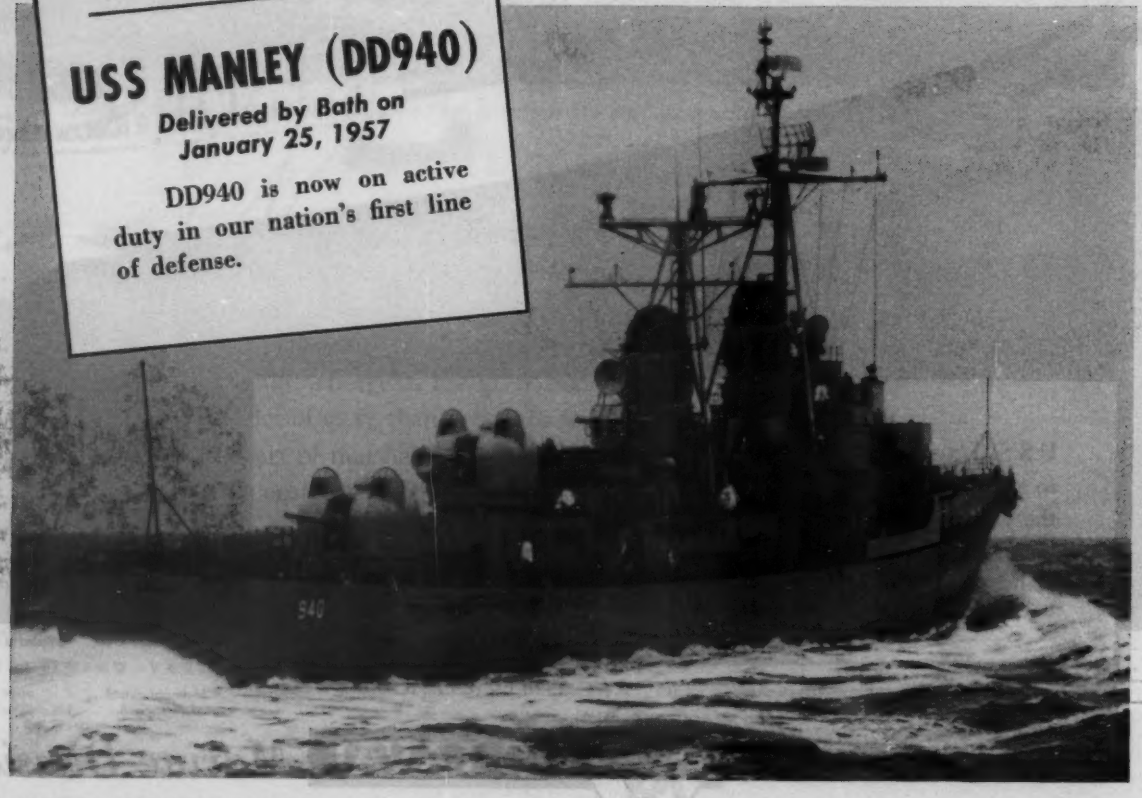

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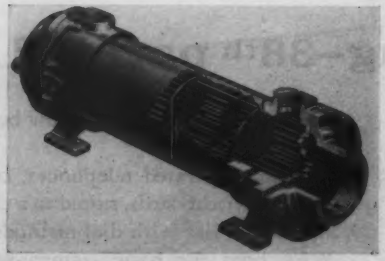

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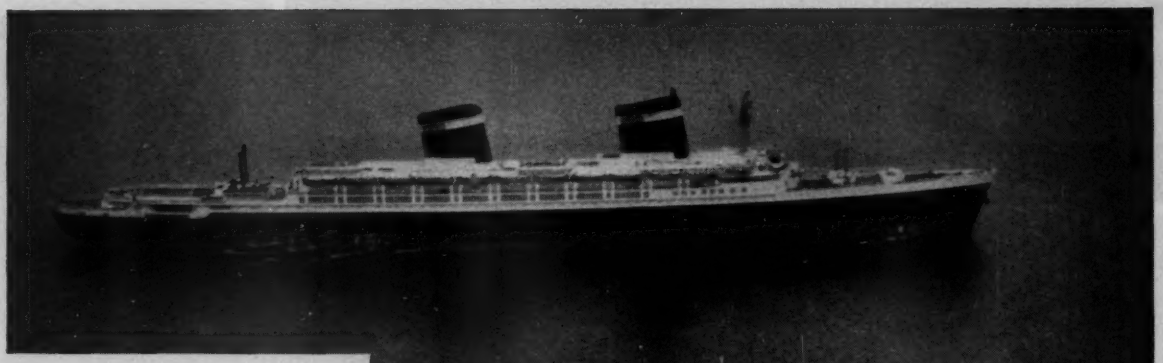

Builder of the nation's largest ships

In the foreground is the mighty 1036-foot aircraft carrier Forrestal. Beyond is the Blue Ribbon winner, the 990-foot liner United States. Warship, luxury passenger liner or whatever the type . . . Newport News has the skill and facilities to build it.

There is complete equipment within the 225-acre plant for the execution of all types of shipbuilding, ship repair and conversion work. Extensive facilities for rapid hull or engine repairs are supplemented by the shipyard's own fully equipped shops for foundry, forging, electrical, sheet metal or joiner work.

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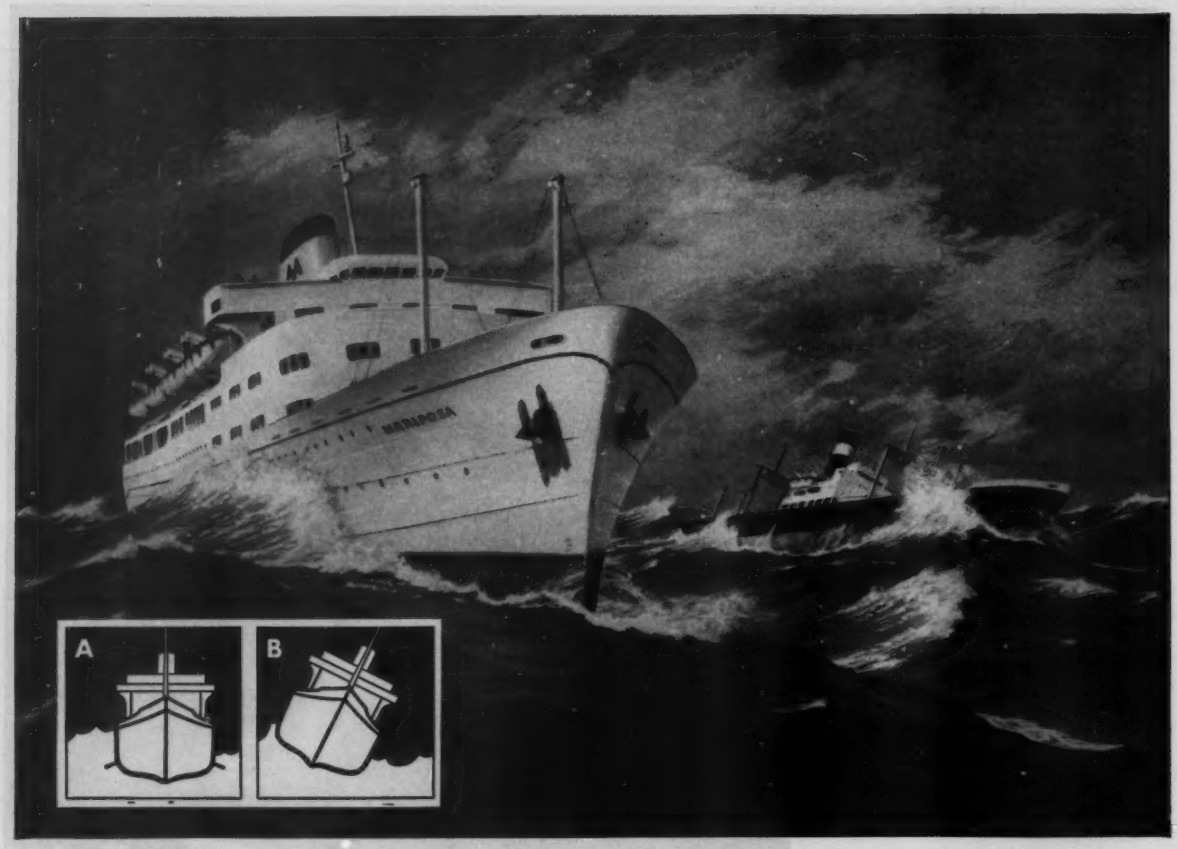
Desirable positions available at Newport News for Designers and Engineers in many categories. Address inquiries to Employment Manager.

Newport News

Shipbuilding and Dry Dock Company

Newport News, Virginia



In rough sea, stabilized ship (A) extends fins to halt up to 90% of roll. It holds course without reducing speed. Unstabilized ship (B) rolls and is forced to cut speed. Newport News Shipbuilding and Dry Dock Company, Newport News, Virginia, built the first two commercial Gyrofins which were installed on the Matson liners, *Mariposa* and *Monterey*. Fabrication techniques included extensive use of rugged, corrosion-resisting Monel nickel-copper alloys.

Gyrofin offsets wave action! Monel offsets sea action!

The twin underwater fins of Sperry's new Gyrofin® Ship Stabilizer produce the "lift" which offsets wave action.

But what protects critical parts of the fin assemblies from the corrosive action of sea water? Sperry uses strong, Seagoin'* Monel* nickel-copper alloys.

Take the "hinge pins" for the flap at the trailing edge of each fin. They must take their full share of *3,000 foot-tons* of anti-rolling movement . . . abrasion, too. So they're extra-strong, extra-hard "K" Monel age-hardenable nickel-copper alloy.

Take the bushing where the fin shaft enters the hull. Its spacer rings are Monel nickel-copper alloy. So are the spacer rings at the fin-flap hinge.

Take the rubbing surface of the hydraulic ram that controls the angle of the flap. It must remain true despite abusive metal-to-metal wear . . . despite salt water attack. Welded Monel overlay (deposited on steel with "140" Monel* Electrode) provides the needed wear and corrosion resistance.

Sperry chose Seagoin' Monel alloys for all these Gyrofin parts because of their strength, toughness, hardness and corrosion resistance.

It will *pay you* to choose Monel alloys for marine equipment, too: for propeller and pump shafts . . . for salt water valves and evaporators . . . for metal fittings and fastenings subject to hard use and corrosive attack.

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What does it do between

HERE and . . .

THERE?

For the first time the behavior pattern of a free space Moving Target can be directly calibrated and immediately evaluated!

The proof of any guided missile is its performance. Not only is it necessary to provide accurate trajectory data in order to determine its effectiveness, but this must be made immediately available.

To meet both requirements is the purpose of the AN/FPS-16 instrumentation radar. This is the first radar developed specifically for Range Instrumentation. It has demonstrated its ability to track with accuracy in darkness, through clouds—under any atmospheric conditions—over extended ranges, and to yield data that can be reduced almost instantaneously to final form. This unit can also be assigned to plot performance of missile, satellite, drone and other free space moving targets.

In the past, this data has depended upon optical devices, triangulation systems with long base lines and precision limitations, modified radar equipment and data reduction methods often requiring months for computation. The immediate availability of data evaluation provided by the AN/FPS-16, now being built by RCA under cognizance of the Navy Bureau of Aeronautics for all services, is a great forward step in Range Instrumentation.

Defense Electronic Products

RADIO CORPORATION of AMERICA

Camden, N. J.

Tmk(s) ®

How new sight for subs helps guard our shores

If enemy planes should ever strike at this continent, it is vital to have as much advance warning as possible.

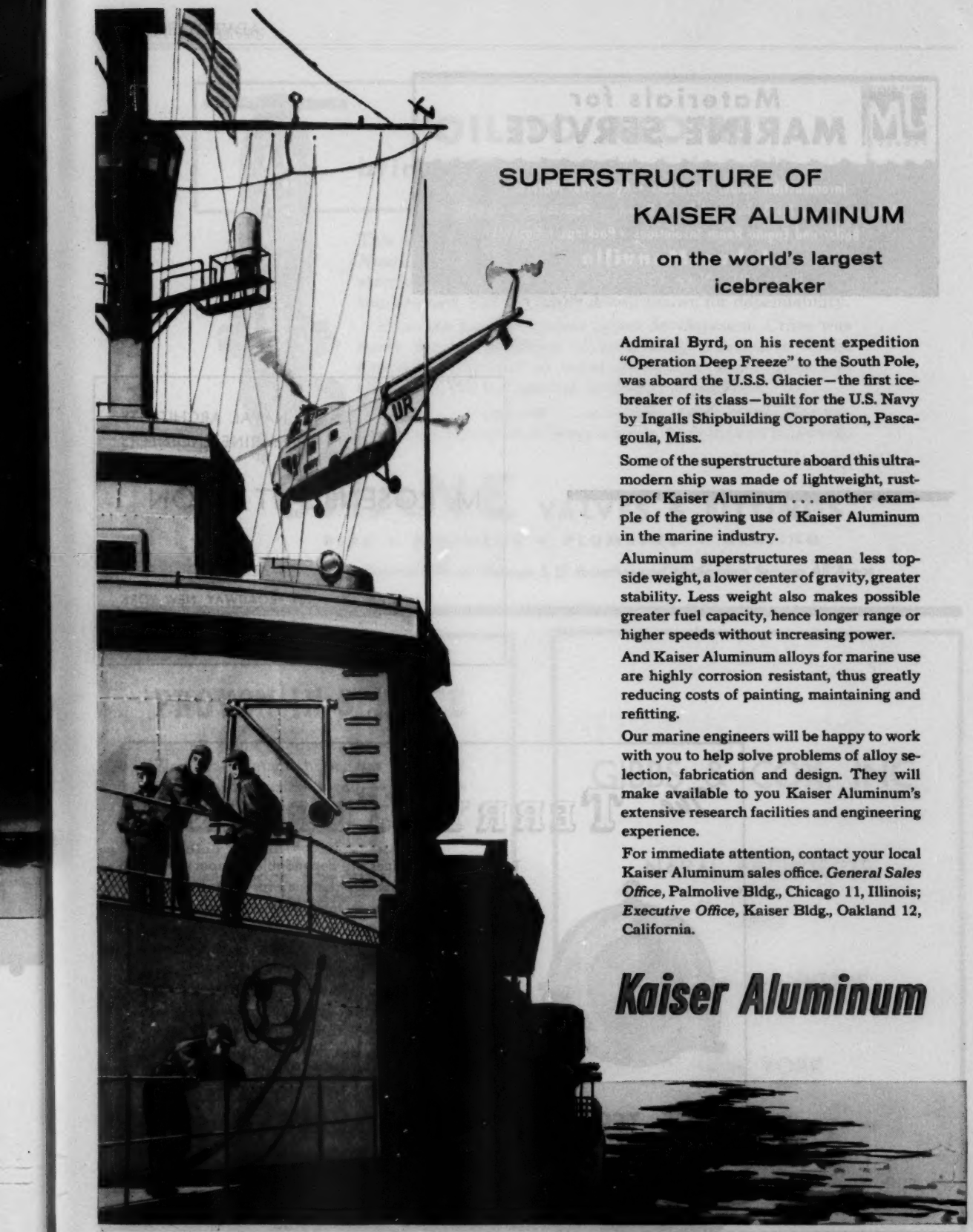
To build flexible coverage, specially designed U. S. Navy picket submarines, like *Salmon* and *Sailfish*, will roam the oceans. Their radars thrust powerful bursts of electronic energy to seek out airborne intruders.

As it was for the DEW line and for the Air Force's B-52, Raytheon was selected to develop special radar for this important duty. Here is another example of how Raytheon's "Excellence in Electronics" is contributing to the nation's security.

RAYTHEON

Excellence in Electronics

RAYTHEON MANUFACTURING COMPANY
Waltham 54, Massachusetts



SUPERSTRUCTURE OF KAISER ALUMINUM

on the world's largest icebreaker

Admiral Byrd, on his recent expedition "Operation Deep Freeze" to the South Pole, was aboard the U.S.S. Glacier—the first icebreaker of its class—built for the U.S. Navy by Ingalls Shipbuilding Corporation, Pascagoula, Miss.

Some of the superstructure aboard this ultramodern ship was made of lightweight, rustproof Kaiser Aluminum . . . another example of the growing use of Kaiser Aluminum in the marine industry.

Aluminum superstructures mean less topside weight, a lower center of gravity, greater stability. Less weight also makes possible greater fuel capacity, hence longer range or higher speeds without increasing power.

And Kaiser Aluminum alloys for marine use are highly corrosion resistant, thus greatly reducing costs of painting, maintaining and refitting.

Our marine engineers will be happy to work with you to help solve problems of alloy selection, fabrication and design. They will make available to you Kaiser Aluminum's extensive research facilities and engineering experience.

For immediate attention, contact your local Kaiser Aluminum sales office. *General Sales Office*, Palmolive Bldg., Chicago 11, Illinois; *Executive Office*, Kaiser Bldg., Oakland 12, California.

Kaiser Aluminum

See "THE KAISER ALUMINUM HOUR." Alternate Tuesdays, NBC Network. Consult your local TV listing.

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Complete details on any turbine application will be gladly furnished.

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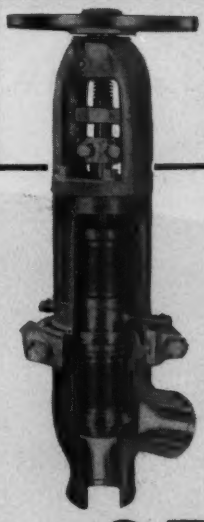

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This is the type of valve found in the engine rooms of the *Nautilus* and the *Seawolf*, and in Navy's plans for added atomic-powered construction. The valve design and application are new, but the brand is well known for dependability.

From the start of nuclear power development, Crane was ready for the problems of controlling radioactive fluids. Crane had the skill in valve metallurgy and engineering. Crane had the background in quality production.

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WELL named the "Universe Leader", this 26-million gallon super-tanker leads any other ship afloat in tonnage and displacement. Although shorter than the Queen Elizabeth, her 125-ft beam, dead weight tonnage of 85,500 and fully loaded displacement of 109,000 tons make the Universe Leader the largest ship ever built, outweighing the USS Forrestal by 10,000 tons. She was built at the Kure Shipyards in Japan for National Bulk Carriers, Inc., N.Y.

Steam power for this record-breaking vessel is provided by Foster Wheeler D Type marine steam generators — each delivering 78,000 lb/hr under normal conditions, and 98,000 lb/hr at peak load. Rated steam pressure is 600 psig, 850 F at the superheater outlet. Furnaces are oil fired and completely water cooled, with 48-inch steam drums over 15 ft in length. An extended surface economizer of the *original* cast-iron design increases feedwater temperature from 280 to 358 F.

From tankers to tugs, aircraft carriers to whaling ships, FW steam generators and condensers are setting the highest standards of dependability and economy the world over. For further information, write to *Foster Wheeler Corporation, 165 Broadway, New York 6, N. Y.*

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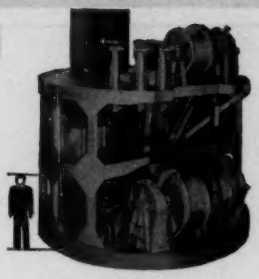
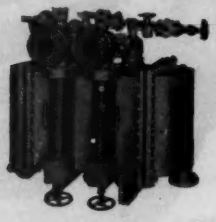
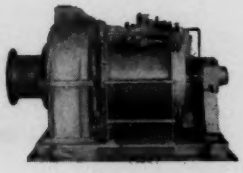


Boat and Airplane Crane

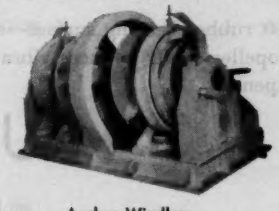


Tubejet Steam Jet Air Ejector



Cargo Winch

Automatic Tensioning Hoist — Airplane Crane



Anchor Windlass

Electric Warping Capstan

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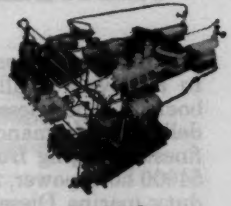
Electric Hydraulic Windlass



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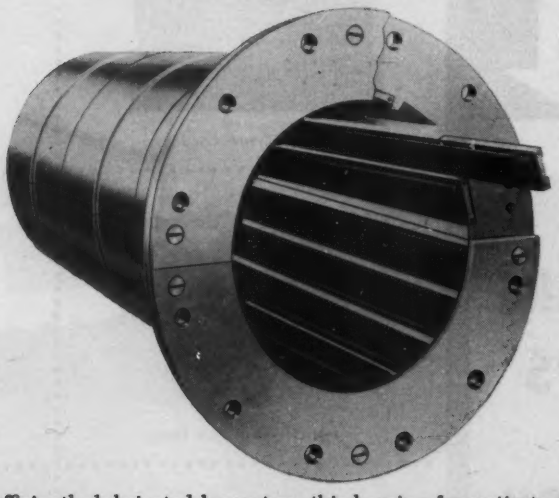

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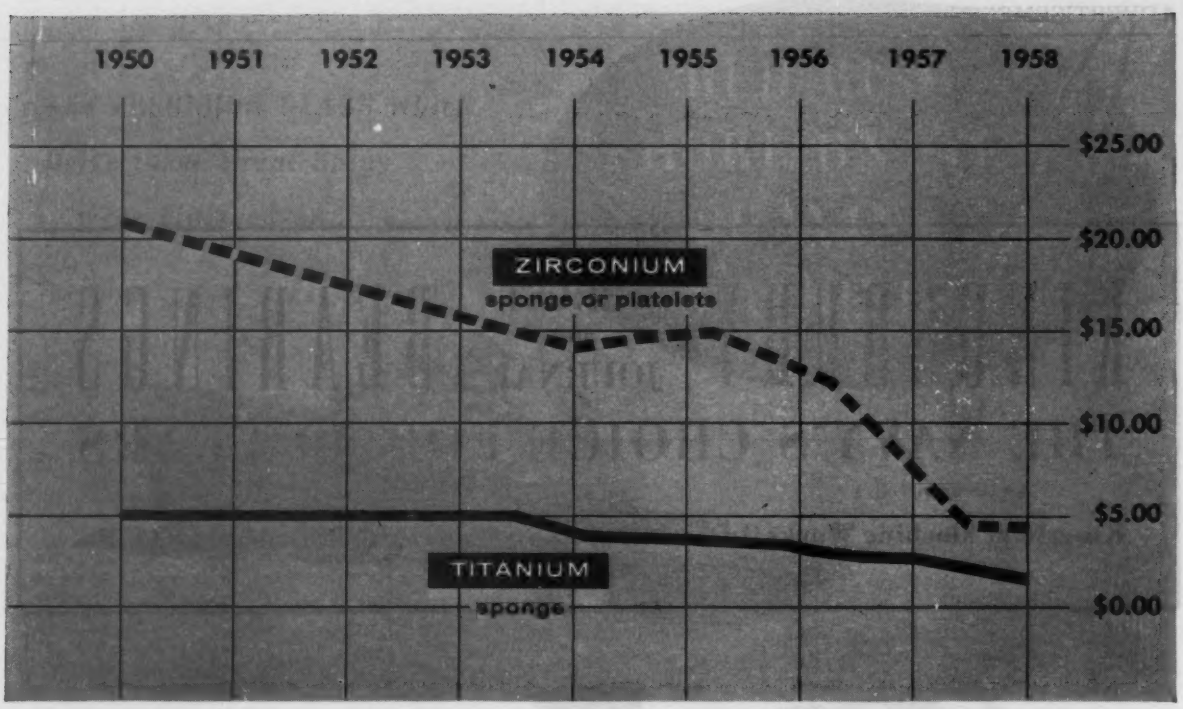

Available soon at lower prices

ZIRCONIUM AND TITANIUM FOR INDUSTRIAL USE

Now is the time to do some new thinking about titanium and zirconium. These metals with their many advantages will soon be *much more plentiful* at *much lower cost.* Reason: U.S.I. will be coming onstream shortly with a 10-million pound per year titanium plant AND a zirconium plant which will supply one million pounds of that metal to industry.

Zirconium from the new plant will sell for considerably less than current prices. Here's why: U.S.I. will use the most economical production technique ever developed for reducing metallic chlorides — a semi-continuous sodium reduction process. This process has possibilities of reducing titanium prices in the future as well.

So think again about zirconium and titanium for industrial equipment. Remember that they are lighter than other metals — a pound goes farther. Remember that they are more durable than other metals—a fabricated product lasts longer.

Write to Bill Greenleaf, U.S.I. Manager of Metals Department, for more information on these new metals from U.S.I.

WHAT CAN YOU DO WITH TITANIUM AND ZIRCONIUM AT LOWER PRICES?

In the future titanium sponge prices are expected to drop to about $2.00 a pound, with a corresponding drop in the prices of mill products. At these prices the exceptional strength-to-weight ratio and corrosion resistance of titanium can be put to work in the aircraft, marine, automotive, chemical and allied fields.

Or consider the eventual price of U.S.I. commercial grade zirconium: an estimated $3.00 a pound for platelets and 2 or 2½ times this price for the average mill product. This price will make zirconium practical for chemical equipment, marine equipment, food equipment and surgical metals among other uses. Zirconium has light weight, high structural strength, excellent corrosion and heat resistance; and reactor-grade zirconium has outstanding nuclear properties.

USI INDUSTRIAL CHEMICALS CO.

Division of National Distillers and Chemical Corporation
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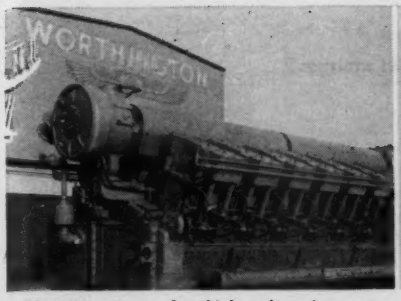

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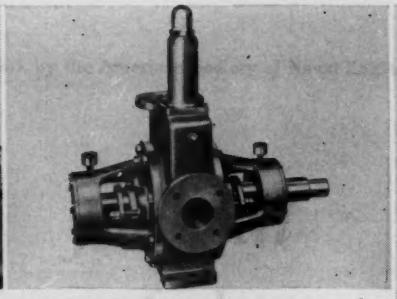

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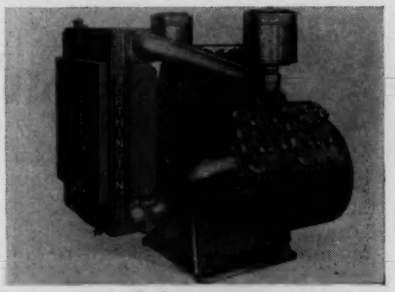
Vertical turbine pumps—for bilge service main cargo and stripping.

Choose from the world's broadest line of shipboard equipment

There are many advantages to selecting shipboard auxiliaries from Worthington's complete line. You can be sure of getting exactly the right equipment to meet your specific requirements. For example, in pumps and compressors alone you have more types than any other manufacturer can supply to choose from. You get the same degree of flexibility in all the many other Worthington products for marine application—some of which are illustrated here.

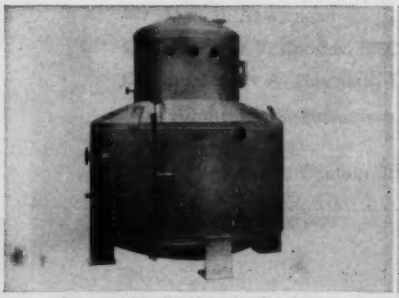
Worthington welcomes the opportunity to help you with special pumping or power problems. And it offers you the advantage of complete product availability and interchangeability anywhere the world over through the services of foreign Worthington companies. Write, outlining your requirements, to Section M62, Worthington Corporation, Marine Division, Harrison, N. J.

M.6.2

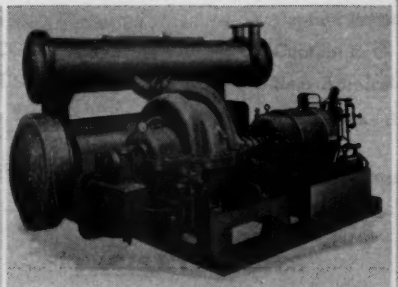


Air Compressors

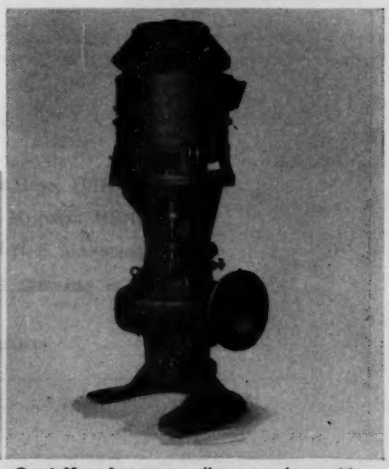
WORTHINGTON



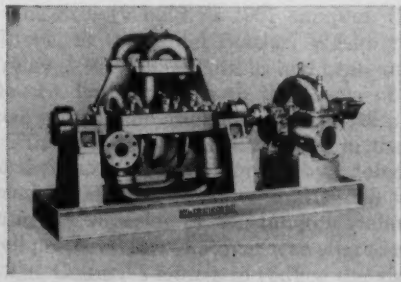
Deaerating feed-water heaters



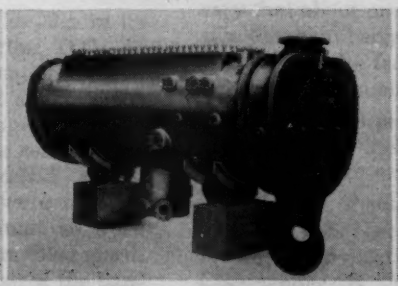
Refrigerating and air conditioning equipment



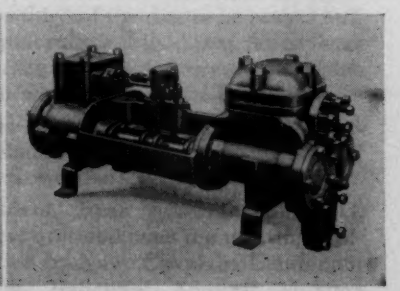
Centrifugal pumps—all types and capacities.



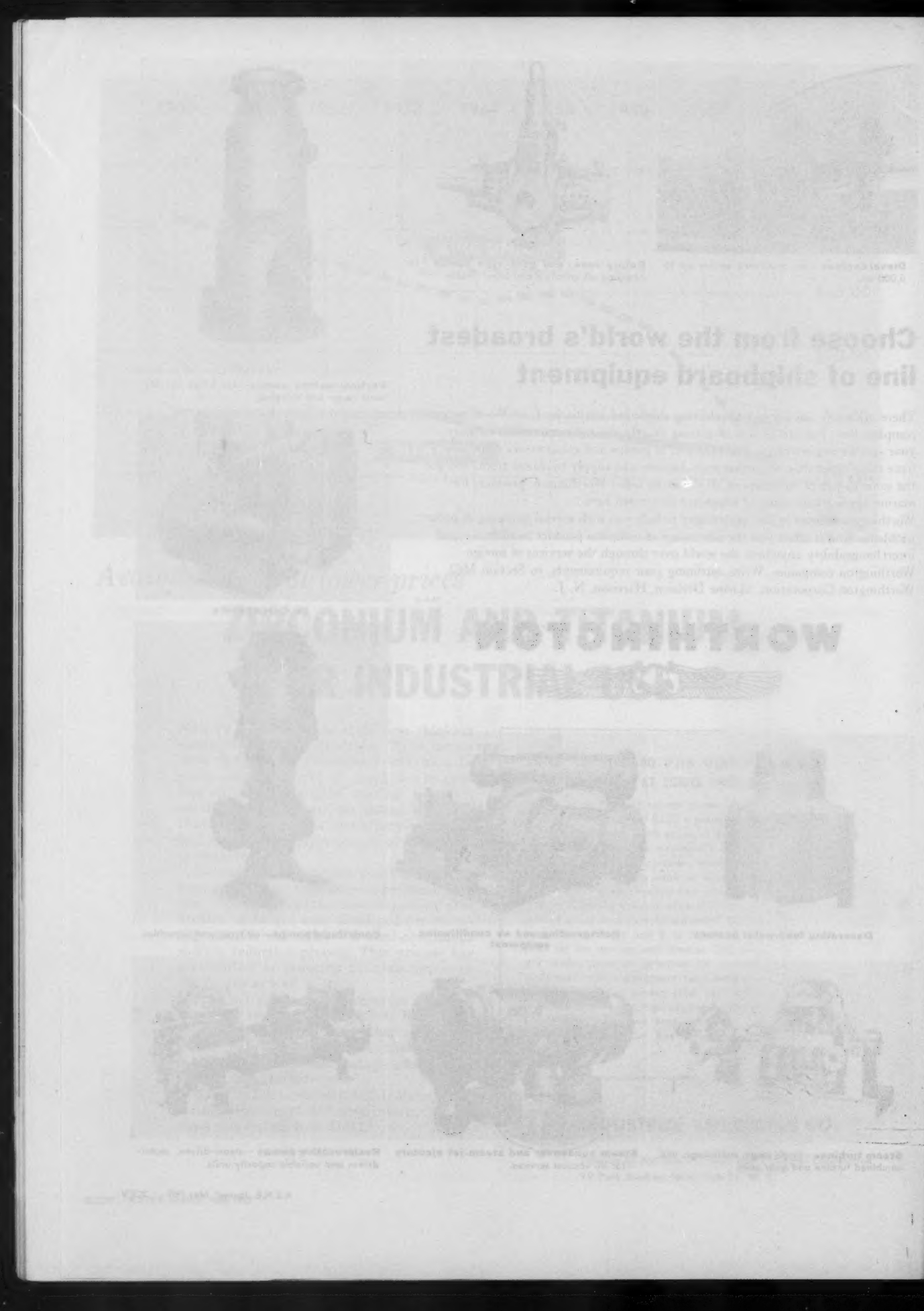
Steam turbines—single-stage, multi-stage, and combined turbine and gear units.



Steam condenser and steam-jet ejectors—for all vacuum services.



Reciprocating pumps—steam-driven, motor-driven and variable capacity units.



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Journal of the AMERICAN SOCIETY of NAVAL ENGINEERS, Inc.

VOLUME 69 MAY 1957 NUMBER 2

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Captain E. G. KINTNER, USNR
Captain JOSEPH A. HARTMAN, USNR
Rear Admiral B. E. MANSEAU, USN
Rear Admiral L. V. HONSINGER, USN
Mr. THOMAS H. SHEPARD, JR.
Captain E. A. WRIGHT, USN
Captain J. E. HAMILTON, USN (Ret.), Secretary-Treasurer

SECRETARY'S NOTES

Annual Banquet

The Society held its 1957 banquet, the 39th in its history, at the Hotel Statler, Washington, D.C., on Friday, 3 May 1957. This, as had been announced previously, was a return to the locale of all banquets from resumption after the war in 1946 until last year.

This banquet was a little later in the season than normal and was favored by delightful spring weather. Most of those who attended were familiar with the vagaries of Washington's climate so were well prepared for whatever was offered in this regard.

The Council's efforts to reduce the size of the banquet were successful but not to the full degree hoped for. The attendance of 1752 was about 200 less than the all time record of 1956. The size made it necessary that about one third of the diners be seated outside the main banquet rooms of the hotel. All of those outside had the facility of a closed circuit TV which kept them in touch with events at the head table.

More than 40 per cent of all Society members attended. These included many past presidents and past secretaries and members of the Council.

The 1957 President, Rear Admiral Albert G. Mumma, U.S. Navy, presided over the meeting. Following the invocation by Navy Chaplain, Lieutenant Commander R. W. Radcliffe, Admiral Mumma greeted members and guests with a few words of welcome.

With the President at the speaker's table were, in addition to the principal speaker:

Past Presidents of the Society:
- 1938—Vice Admiral Harold G. Bowen, U.S. Navy, Retired
- 1946—Rear Admiral Henry Williams, U.S. Navy, Retired
- 1946—Rear Admiral Harvey F. Johnson, U.S. Coast Guard, Retired
- 1948—Rear Admiral Roger W. Paine, U.S. Navy, Retired
- 1954—Rear Admiral Evander W. Sylvester, U.S. Navy, Retired
- 1955—Rear Admiral W. D. Leggett, Jr., U.S. Navy, Retired
- 1955—Rear Admiral F. R. Furth, U.S. Navy, Retired
- 1956—Rear Admiral Kenneth K. Cowart, U.S. Coast Guard

Captain Henry C. Dinger, U.S. Navy, Retired, who was appointed Secretary-Treasurer in October 1908 and elected for 1909 and 1910 is the earliest past Secretary-Treasurer still living.

Honorary members:
- Mr. Arthur G. Fessenden
- Mr. Donald Herr

Mr. Wilfred J. McNeil, Assistant Secretary of Defense and Comptroller of the Department of Defense.

Vice Admiral Herbert G. Hopwood, U.S. Navy, Deputy Chief of Naval Operation for Logistics.

Navy Chiefs of Bureaus:
- Rear Admiral R. J. Arnold, Supply Corps, U.S. Navy, Bureau of Supplies and Accounts
- Rear Admiral R. H. Meade, Civil Engineer Corps, U.S. Navy, Bureau of Yards and Docks
- Rear Admiral F. S. Withingtoi, U.S. Navy, Bureau of Ordnance

Rear Admiral H. D. Baker, Commandant of the Potomac River Naval Command.

Mr. Herbert G. Blunck, one of Washington's civic leaders and as General Manager of the Hotel Statler, "Ye Hoste" to the Society for the evening.

Other Past-Presidents, Past-Secretary-Treasurers, Chiefs of Navy Bureaus, members of the Defense Secretariat, senior members of the military command and industrial, business, civil and political leaders were among the guests who were seated with other parties throughout the main and auxiliary rooms. It is the presence of so many distinguished people which makes it so difficult for a toastmaster to know just how far to go in making introductions. At this banquet this was handled by a general introduction and naming of only those who were seated at the head table.

The Principal Speaker

It had been announced that Vice Admiral Earle W. Mills, U.S. Navy, Retired and 1945 Past-President, would be the principal speaker. Unavoidable business commitments in Japan and Alaska interfered and Admiral Mills was unable to attend. This became known too late to correct the announcement which appeared in the February JOURNAL; but not too late to permit obtaining a speaker of eminent stature.

Lieutenant General Lewis B. Hershey, U.S. Army, Director of Selective Service of the United States, is a national figure of prominence. His ability as a director of mammoth operations which are ticklish yet vital because of their impact on individual lives and their importance to the nation is well known. Perhaps the best attestation of this is the fact that one week before the banquet, General Hershey received an award from the Society of Military Chaplains because he had maintained spiritual values throughout his handling of Selective Service.

General Hershey announced, as the subject of his talk, "Specialized Manpower," a matter of extreme current importance and critical today in the affairs of both the civilian and military naval engineers who attended the banquet. Those present had the privilege of hearing a talk which was provocative yet entertaining, short yet effective, instructive and educational yet interesting. They were indeed fortunate.

We regret very much that General Hershey's talk cannot be printed in full in the JOURNAL for the benefit of those who were unable to attend. These are thus deprived of a message which is important to all. The highlights of the talk were (admittedly the selection of these is subjective to the editors):

General Hershey enunciated the thesis that there exists a relationship between the things we do not understand and the things we respect. For instance, the minister perhaps suffers some diminishment in the respect of the public because we believe he knows exactly *where* we are going. The doctor perhaps bears some loss of respect because we believe he knows exactly *when* we are going. The engineer, on the other hand, is identified with ingenuity, and the public does not fully understand this. It does not fully understand, for instance, how he can construct —in a short time and on a beautiful countryside,— a tremendous plant which can so quickly pollute the surrounding waterways and fill the atmosphere with an unbearable stench!

Turning to the engineer problem, the speaker pointed out that the first requisite to its solution is its accurate identification—in itself a difficult and, as yet, unsolved problem. For instance, the difficulty of engineer procurement is world-wide. The Russians have developed a system of incentives to encourage youth to study engineering—in short, they are using a capitalistic approach to the problem. In the United States, on the other hand, the educational system does not provide the necessary incentive to lure the student into the study of engineering. Modern educational methods in this country place no premium upon the attainment of the difficult. In short, the United States—a capitalistic country—is using socialistic educational methods.

Developing this theme, General Hershey stated that engineers in adequate numbers, with adequate education and training, and used in properly oriented effort, are essential to the survival of this country. One of our difficulties stems from the fact that a great quantity of engineering talent is being siphoned off into non-essential effort. The speaker cited, as a probable instance, the amount of engineering effort devoted to the design of the tail-fins on the 1957 automobiles, and the tremendous engineering effort being fed into the highly competitive fields which contribute so much more to the satisfaction of personal creature comforts, such as household appliances, air conditioning and television, than they do to either the defensive strength of the Nation or the spiritual welfare of the individual.

This constitutes an absence of the attitude of what the speaker called "long range selfishness," which is necessary for us as a nation to maintain for ultimate survival. Failing the maintenance of this attitude, as a national discipline, General Hershey presented two alternatives:

1. National regimentation of manpower, in order to insure the cultivation of necessary talent—an unthinkable alternative for us as a democracy, or
2. The ultimate failure and disappearance of this nation.

As a solution to the problem, General Hershey proposed that first, the educational system must be made to provide a firm foundation in the fundamentals at the secondary level. The fact that learning—and teaching—some of these fundamentals may be an unpleasant process should not be allowed to deter their inclusion: the teacher and student alike must accept the fact that certain unpleasant things must be endured in secondary education.

Second, complete trustworthiness should be placed at the top of the priority list in our national training. The development of this trait of character is of prime importance.

Third, a firm sense of responsibility is essential—by industry in the use of engineers—and by individuals in the use of their own knowledge and training.

Awards

Shortly after the appearance of this issue of the JOURNAL, another school year will close and various awards will be made to the students who best meet certain criteria. These awards which are of interest to the Society include its own ASNE awards which are made to a graduate of each of the service academies:

U.S. Naval Academy, Annapolis, Md.
U.S. Coast Guard Academy, New London, Conn.
U.S. Merchant Marine Academy, Kings Point, N.Y.

Announcement of the names of winners of these awards will have to go forward to the August issue.

Other awards are:

The **Brand** award to be made to the officer student who stands first in his class in Course XIII-A at the Massachusetts Institute of Technology, and

The **Lamb** award to the "Outstanding NROTC Senior Student" in the School of Engineering of the University of Tulane.

Announcement of the Brand award will be made in the August issue.

The winner of the Lamb award has been selected. The award is made by Captain Carl J. Lamb, USNR, a very active member of the Society, and consists of a starting membership in the Society. The award will be made on 29 May 1957 to

Midshipman William Soland Vorhaben who will be commissioned as an Ensign, USNR.

Council Meeting

Meetings of the Council were held on 6 March and on 24 April 1957. Members who follow the Secretary's Notes will note that it is becoming necessary for the Council to meet with increasing frequency. Part of this is due to the growth of the Society but a large part is forced because of the rapidly increasing complexity of the broad social and economic environment within which the Society operates.

The Society is too small to utilize the advanced methods of office administration which have become available, yet it has become too large to continue effectively as a "one-man" operation. For nearly 50 years, one man has been able to keep things going under the supervision of the elected, part-time, Secretary-Treasurer and few matters have had to be placed before the Council for decision. This has now changed and decisions must be made.

As a beginning, at the meeting on 6 March, the President appointed a committee, headed by Rear Admiral L. V. Honsinger, U.S. Navy, with Captain E. A. Wright, USN, and Captain J. A. Hartman, USNR as members, to study the by-laws and make recommendations as to changes in them. This study is to include finances and dues. At the 24 April meeting, the committee was not ready to make a final report but did submit a number of recommended changes in the by-laws. These have been tabled for consideration by the Council. Those which are approved will be submitted to the full membership for decision probably in June or July 1957.

At the meeting on 24 April, the President appointed another committee, headed by the Secretary-Treasurer and with Captain E. G. Kintner, USNR, and Mr. J. B. Armstrong, members, to recommend an investment policy for the Society. The present policy was set down during the war. It provided that all reserve funds be invested in Federal Government Bonds. As these began to mature last year, an interim policy of placing the released funds in guaranteed Building and Loan associations was adopted.

It is hoped that both committees will be in a position to submit final reports to the Council at its next meeting, tentatively scheduled for 12 June 1957.

Changes in the Council

Because of official orders which will remove certain Council members from Washington, D.C., the Council took the following action:

On about 20 May, 1957, Captain R. D. Schmidtman, USCG, will become a Council member, vice Captain Peter V. Colmar, USCG, to serve out his term which expires on 31 December 1957.

On about 1 July 1957, Captain Kenneth Ayres, USNR, will become a Council member, vice Captain E. G. Kintner, USNR, to serve out his term which also expires on 31 December 1957.

Chief of Naval Research

Appearing in these pages are "Reminiscences" of Admiral H. G. Bowen who was the first Chief of Naval Research. It is of interest to this Society that three of the six officers who have held this office have also been Presidents of this Society and two of the others have served on the Council.

Navy League Awards of Merit

The Navy League of the United States has recently established four awards of merit to be awarded annually to personnel military or civilian of the Navy. The awards are in the following fields: 1. Inspirational leadership to be awarded to that naval officer, Marine Corps officer or enlisted man who has made an outstanding contribution to the high standards of leadership traditional in the Navy; 2. Scientific development and technical progress to be awarded to that naval officer or Marine Corps officer, enlisted man or civilian who has made an outstanding contribution in any field of science which has furthered the development and progress of the Navy; 3. Planning and operational competence to be awarded to that naval officer, Marine Corps officer or enlisted man who has made an outstanding personal contribution in the course of actual naval operations which has advanced the readiness and competence of the naval service; 4. Literary achievement to be awarded to that naval officer, Marine Corps officer, enlisted man or civilian who has made a notable literary contribution which has advanced the knowledge of the importance of seapower to the United States. Civilian nominees do not have to be Navy or Marine Corps employees. Each award consists of an appropriate certificate plus an inscribed diamond-studded wrist watch.

The Navy League Board of Awards consists of a former Secretary of the Navy, a former Chief of Naval Operations, a retired Admiral, and an outstanding business leader.

It appears that awards in the second category should be of interest to members of the Society.

Industrial College of the Armed Forces

The Industrial College of the Armed Forces, one of the three Joint educational institutions of the Departmentn of Defense, wishes to call attention to the Correspondence Course which it offers to Regular and Reserve Officers, National Guard Officers, and to civilian executives both in industry and government. This extension course, "Emergency Management of the National Economy," is designed to reach the civilian community and those members of the military services who cannot attend the Resident Course conducted by the Industrial College of the Armed Forces. The Resident Course is restricted to a limited number of of senior officers on active duty nominted by their respective services, and civilian government officials.

The objective of the Correspondence Course is to educate key personnel to the all important civilian-military relationship upon which the nation depends in this era of constant readiness. This close relationship is stressed by the Industrial College of the Armed Forces. The two are indeed inseparable and there must be the highest degree of cooperation and understanding.

Immediate benefits can and do accrue to enrollees. The graduates of this unique course are better informed and therefore more capable of understanding the significance of national and international happenings.

Both the textbooks and examinations used in the course emphasize and explain the interdepeendence and relationship of the many separate subject areas which have an important bearing on economic readiness.

Although many persons, both military and civilian, have been directly or indirectly connected with a mobilization effort, either during World War II or the Korean confiict, few have had an opportunity to observe directly the interrelationship of the various aspects of economic readiness.

A certificate of completion is awarded by the Industrial College of the Armed Forces to every student who successfully completes the course.

Credit points have been authorized by the military services for retention, promotion, and retirement for reservists not on active duty. Forty-eight points are awarded for completion of the course. All graduates of the course may retain the textbooks, which are available through no other source and constitute a valuable addition to the personal library of anyone concerned with the future of the military, the nation's economy and the world situation as it affects our plans and policies.

Those who wish to enroll may communicate directly with the Correspondence Study Branch, Industrial College of the Armed Forces, Washington 25, D.C. A prospectus will be forwarded which outlines the eligibility requirements and includes an application form and necessary instructions.

CAPTAIN E. A. WRIGHT, USN

NAVAL MATHEMATICS AT THE DAVID TAYLOR MODEL BASIN

THE AUTHOR

an Engineering Duty Officer of the United States Navy, was graduated from the U.S. Naval Academy in 1931. He served five years at sea in USS Pensacola, Chicago and Jacob Jones, particularly in naval engineering, before postgraduate instruction at the Massachusetts Institute of Technology leading to the degree of Master of Science in Naval Construction. In recent years, Captain Wright has been head of Hull Design in the Bureau of Ships, Senior Assistant Fleet Maintenance Officer on the Staff of Commander Service Force, U.S. Pacific Fleet, and Production Officer at the Mare Island Naval Shipyard. He is now Commanding Officer and Director of the David Taylor Model Basin, and Council Member of the American Society of Naval Engineers.

EDITOR'S NOTE

Payment to the author for this manuscript will be given by him as a David Taylor Model Basin Science Award to the outstanding science student, Class of 1957, in each high school in Montgomery County, Maryland.

NAVAL ENGINEERING is acquiring a new dimension. Across the face of our profession, rooted in mathematics and embracing every physical science, is quietly bursting a tremendous new versatility and power that will surely carry naval engineering far beyond present design frontiers. It is the rapid automation of ship calculations in every conceivable and yet unconceived direction. This young dimension might be called naval mathematics.

The new automative force is unfettering the hands and mind of the naval engineer, long circumscribed by slide rule, desk calculator and manual plotting. He is finding not only personal emancipation from routine calculations, but an astounding increase in his effective working force in the face of national shortage of engineers and scientists. Under these buoyant conditions, he is further inspired by the new vistas of untouched research, development and engineering heretofore far beyond his reach. For the first time, the seaworthiness of surface ships can be approached concurrently through theory and the mathematical analysis of observed ship motions, dynamic hull strains, and the energy spectrum of the sea surface. Naval mathematics is the vital partner of ship reactor design in the calculation of heat transfer patterns, control rod effects, and burnout. Even nonmathematical ship lines may soon be faired on universal computers, and tables of off-sets produced.

The teamwork of mathematicians, theorists, and naval engineers is discovering unsuspected areas for systematizing scientific and design calculations. From calculating pipe stresses to potential flow patterns around submerged bodies, from decompression tables to radioactivity levels, from machinery vibration to casualty rates for electronic components, and from extrapolation of ship model observations to analysis of fuel rates for ships of the U.S. Navy, the scope of naval mathematics ever widens. The workhorses of this numerical revolution are the universal computers, which are each the equivalent of more than 1000 skilled humans with desk calculators, which produce for a 110-vice 40-hour work week, which require no sick or annual leave, which make few mistakes and have excellent memory, which have comparatively few management problems, and which do not even take a coffee break.

The purposes of this paper are to describe:

(a) the pioneering development by the Bureau of Ships of the Applied Mathematics Laboratory at the David Taylor Model Basin.

(b) typical large universal computers that have and will become our co-workers, and

(c) several of the ship design, building and operating areas in which naval mathematics and engineering are presently collaborating.

To emphasize the position and prospect of large universal computers in naval mathematics, this paper does not treat the analogue computers which are now widely useful in the ship industry, nor the medium and small digital computers which already deliver so much daily bread.

I. APPLIED MATHEMATICS LABORATORY

Throughout the jet rise of large-scale digital computers, the Bureau of Ships of the Navy Department has been a leading and forward-looking sponsor. It was the Chief of the Bureau of Ships who, just 13 years ago, sponsored operation of the first automatic digital computer in the United States at Harvard University's Cruft Laboratory. Fittingly, the Harvard Mark I calculator was designed and constructed by then Commander Howard Aiken, United States Navy, in collaboration with International Business Machines Corporation. Some of the first engineering problems solved in this machine originated in the Bureau of Ships.

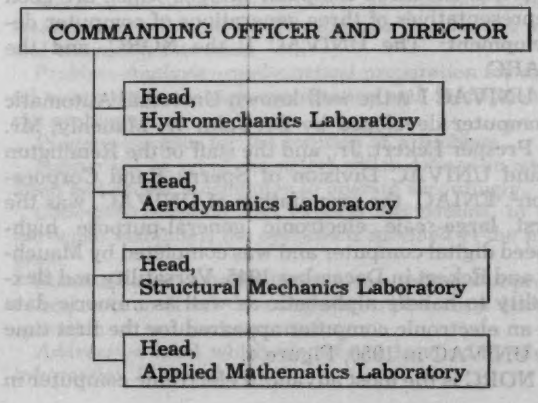
In June 1952, the Bureau of Ships decided to set up its own computer laboratory at the David Taylor Model Basin. Concurrently with formalizing an Electronic Computer Branch of the Bureau of Ships the Applied Mathematics Laboratory of the David Taylor Model Basin was established on 8 December 1952. Construction of the laboratory building began that month and was completed in May 1953, along with completion of the factory acceptance test of UNIVAC. Installation of the computer began immediately, and it was in operation by August 1953. The Applied Mathematics Laboratory was dedicated 16 October 1953[1], Figure 1.

Figure 1. Rear Admiral W. D. Leggett, USN, Chief of the Bureau of Ships at the time, dedicates the DTMB Applied Mathematics Laboratory on 16 October 1953. At left is Captain A. G. Mumma, USN, Commanding Officer and Director and now Rear Admiral, Chief of the Bureau of Ships and President of The Society; and at right Dr. J. W. Mauchly, co-designer of UNIVAC and Dr. H. Polachek, Chief Mathematician. Among the guests were Major General Leslie R. Groves, U. S. Army (Ret.), former head of the Manhattan Project, Rear Admiral M. L. Royar (SC), USN, Chief of the Bureau of Supplies and Accounts, and Captain F. R. Furth, USN, later Chief of Naval Research.

Figure 2. Rear Admiral H. D. Baker, USN, Commandant of the Potomac River Naval Command, questions Dr. Harry Polachek, Head of the DTMB Applied Mathematics Laboratory, on steps in the computer solution of survivor benefits for personnel of the Armed Services, and on plans for installation in 1958 of the Large Automatic Research Calculator (LARC).

Original staffing of 30 civilian employees in the Applied Mathematics Laboratory, exclusive of the various supporting departments of the David Taylor Model Basin, contemplated 1-shift operation of UNIVAC. Within 3 months of the dedication, the Laboratory accelerated to 2-shift operation in response to demand for computing service, then to 3 shifts in January 1954. Beginning in August 1955, additional time has been scheduled in ever increasing amounts on the NORC at the Naval Proving Ground at Dahlgren, Virginia. A second UNIVAC was installed at the David Taylor Model Basin in February 1956. In calendar 1956, a total of 3300 hours of productive computer time were provided by the two UNIVAC's at Carderock and 1350 hours were utilized on NORC at Dahlgren. At year's end, the staff of the Applied Mathematic Laboratory numbered 90. The manning target for July 1957 is 120 employees, in preparation for the delivery of the LARC computer in 1958, Figure 2.

Organizationally, Applied Mathematics is a member of a quartet of the laboratories of the David Taylor Model Basin:



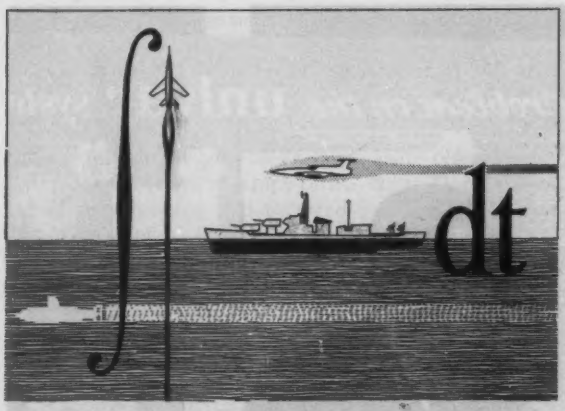
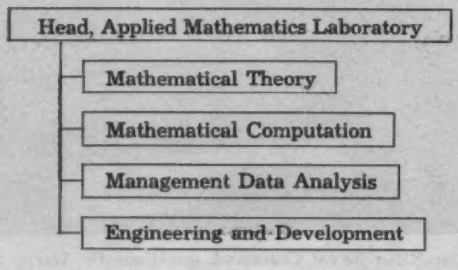


Figure 3. Naval mathematics integrates research in ships and aircraft at the David Taylor Model Basin, all the way from submarines to guided missiles.

So significant has the contribution and integrating effect of naval mathematics become that a new symbol of the David Taylor Model Basin, to be used as a kind of trademark, may take the form of Figure 3.

Internal organization of the Applied Mathematics Laboratory provides 4 functional divisions:



The Theory Division conducts research in numerical techniques for high-speed calculation, applied mathematics and statistics, and serves as consultants in these fields. The Mathematical Computation Division analyzes, programs, and carries out the solution of engineering research problems, while the Management Data Analysis Division does the same in the fields of logistics and management. The Engineering Development Division operates, maintains, and continually improves the universal computer systems.

The mission of the Applied Mathematics Laboratory includes responsibility for research in mathematical analysis and computer techniques in order to extend the utility of high-speed digital devices to the solution of scientific, engineering, logistic and management problems of the Bureau of Ships. Therefore, in addition to providing computer service, training and advice to the Bureau, its field activities, and its contractors, the DTMB Applied Mathematics Laboratory spearheads and triggers progress for the Bureau through research in mathematics. For example, a procedure for computer handling of the logistics of machinery replacement parts was first developed at the Model Basin. Such a procedure is now in use at the Ships Parts Control Center, Mechanicsburg, Pennsylvania. At the other end of the application spectrum, a technique is being developed for predicting the performance of wake-adapted contra-rotating propellers.

II. THE MACHINES

Let us turn now to the large electronic universal digital computers, which provide thousands of Indians, who move with the speed of light, to serve the few human chiefs of the AML tribe. It so happens that the Applied Mathematics Laboratory has used and will use three computer designs which are good representatives of three generations of computer development: The UNIVAC I, the NORC, and the LARC.

UNIVAC I is the well-known Universal Automatic Computer developed by Dr. John W. Mauchly, Mr. J. Presper Eckert, Jr., and the staff of the Remington Rand UNIVAC Division of Sperry Rand Corporation[2]. ENIAC, the grandfather of UNIVAC, was the first large-scale electronic general-purpose high-speed digital computer and was completed by Mauchly and Eckert in December 1945. Versatility and flexibility to handle alphabetic as well as numeric data in an electronic computer appeared for the first time in UNIVAC in 1950, Figure 4.

NORC is the most advanced electronic computer in operation in the world today, Figure 5. The Naval Ordnance Research Calculator was designed and constructed by International Business Machines Corporation[3] to meet the needs of the Bureau of Ordnance, and was put into operation at the Naval Proving Ground at Dahlgren, Virginia, in 1954. Over one-third of the productive time of this machine is now made available to the DTMB Applied Mathematics Laboratory on work for the Bureau of Ships.

LARC is a Large Automatic Research Calculator currently being developed by the Remington Rand UNIVAC Division of Sperry Rand Corporation[4]. The first of these machines, ordered by the Atomic Energy Commission, will go to the Radiation Laboratory of the University of California at Livermore, California. The second LARC, ordered by the Bureau of Ships, will go to the Applied Mathematics Laboratory of the David Taylor Model Basin, Figure 6. Delivery of both computers is expected in 1958.

The generation of each of these three representative general purpose computers is suggested signifi-

Figure 4. From the control console, the operator can initiate and interrupt programs, receive warning indications, search for errors in logic or internal operation, and monitor the machine through the oscilloscope on the left and typer on the right. In the background are the magnetic tapes on servos for input to and output from the central computer of UNIVAC.

cantly by their speed of internal operation:

Computer	Date	Multiplications Per Second
UNIVAC	1950	700
NORC	1954	13,000
LARC	1958	100,000

Never has man accelerated a servant, be it boat or motor car or airplane or missile, at such a rate.

A comprehensive description of digital computer development through 1948 was presented to the American Society of Naval Engineers by Albert E. Smith and C. V. L. Smith[5]. This section of the present paper therefore reviews only a few fundamentals of computers to serve as a basis for presenting the particular characteristics of UNIVAC, NORC and LARC which belong after the turn of the century.

Computer Terms

For reference as needed in the discussion following, mention is made of frequent computer terms and principal electronic building blocks[6,7]:

Bit—a binary digit.

Pulse—voltage level, of short duration, used in computers to represent a bit.

Pulse Time—period of time required to represent a binary digit.

Character—a group of pulses usually used to represent a decimal digit, letter, punctuation, or other symbol.

Word—a set of characters which occupies one storage location and is treated by the computer circuits as a unit and transported as such.

Problem Analysis—mathematical preparation for digital computation through examination and description of the problem.

Program—a plan for the solution of a problem.

Instruction—a set of characters which defines an operation and causes a computer to operate accordingly.

Coding—translation into explicit instructions, to the particular computer, the operations specified in the program.

Routine—a set of coded instructions arranged in proper sequence to direct the computer to perform a desired operation or series of operations.

Address—a label which identifies a location in which information is stored.

Figure 5. IBM's NORC, the most powerful large-scale electronic computer in the world today. In the foreground is one of two 18,000 character/minute printers. The operator, seated at the control console, faces the logical and arithmetical section.

Double Precision—a quantity having twice as many digits as are normally carried in a specific computer.

Input—information transferred from external storage into the internal storage of a computer.

Edit—to rearrange computed information.

Operand—any one of the quantities entering or arising in an operation.

Flip-Flop (FF)—a static storage device possessing two states.

Gate (G)—permits or prohibits the passage of a pulse signal from one point to another; sometimes called "AND" circuits because they require the presence of Signal X and Signal Y in order to pass Signal Z.

Buffer (B)—combines several pulse sources into line without interaction among the sources; sometimes called "OR" gate because either Signal X or Signal Y is allowed to pass.

Delay (D)—stores the pulse signal the desired time; important to bring about the synchronous arrival or departure of several signals.

Binary Counter (BC)—indicates at any time how many pulses have been received.

Pulse Former (PFR)—adds the energy of circulation to the system, and re-establishes the shape and timing of the pulses.

Register—device for temporary storage of one or more computer words; used also as a counter or arithmetic register in which case it can actually add.

Magnitude Comparator—a circuit to decide the identity or relative magnitude of two quantities.

Complementer—a circuit which complements a number in any system.

Half Adder—a circuit having two inputs and two outputs, that combines two trains of pulses and produces their sum or carry pulses.

Function Table (FT)—a device which can decode many input lines into a single output line, or encode a single input line into many output lines.

Digital Arithmetic

Dual choice is the basic operation underlying all large electronic computers. Whereas our traditional arithmetic has ten choices, from 0 to 9, the calculating components of most digital machines make only 2 choices, as 0 or 1, off or on, blank or dot.

Some computers use the pure binary system, such as the Sperry Rand ERA 1103, or the IBM 701 or 704. NORC, LARC and UNIVAC are designed to use some form of the binary coded decimal system.

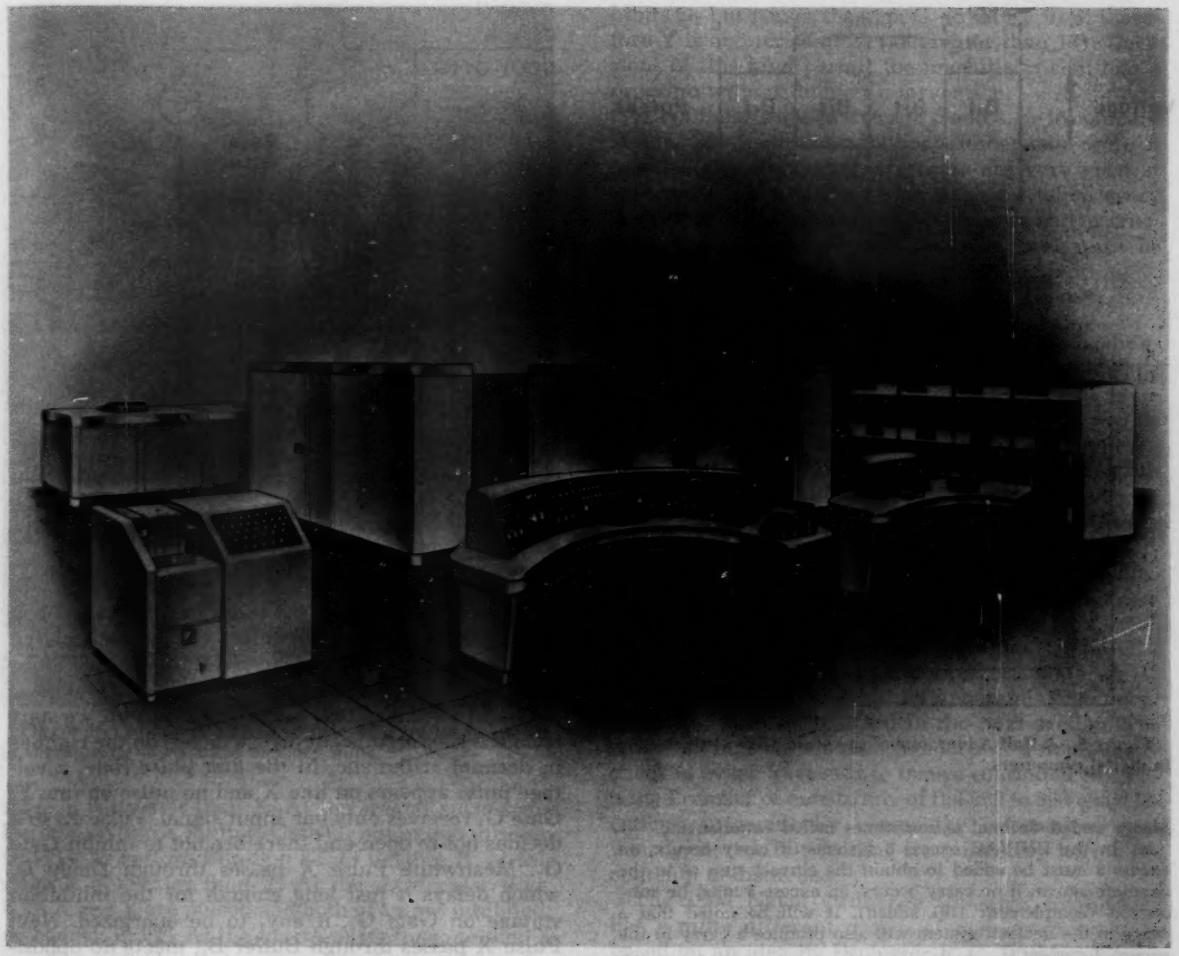


Figure 6. Artist's conception of the Remington Rand LARC. The engineer's and operator's control units are shown in the right and left foreground. To the left is an on-line printer. In the background are tape servos, main memory stacks, processor, computing unit, and drum files. This photograph may not necessarily represent the actual items to be delivered.

UNIVAC employs a modified binary coded decimal system in which each decimal digit is represented in binary by its original value plus 3. Comparative sequences are:

Decimal	Binary	NORC Binary Coded Decimal	UNIVAC Excess 3 System
0	0000	0000	0011
1	0001	0001	0100
2	0010	0010	0101
3	0011	0011	0110
4	0100	0100	0111
5	0101	0101	1000
6	0110	0110	1001
7	0111	0111	1010
8	1000	1000	1011
9	1001	1001	1100
10	1010	0001 0000	0100 0011
11	1011	0001 0001	0100 0100
12	1100	0001 0010	0100 0101
13	1101	0001 0011	0100 0110
14	1110	0001 0100	0100 0111
15	1111	0001 0101	0100 1000
16	10000	0001 0110	0100 1001

An easy means of converting from binary to decimal is by powers of 2 as:

Binary 1001 = Decimal 9

$(1 \times 2^3) + (0 \times 2^2) + (0 \times 2^1) + (1 \times 2^0) =$

$8 + 0 + 0 + 1 = 9$

A binary digit is called a bit. The particular arrangement of bits peculiar to UNIVAC, NORC and LARC will be described under Pulse Wording.

Addition in binary arithmetic is simply $0 + 0 = 0$, $0 + 1 = 1$ and $1 + 1 = 0$ with 1 to carry, as:

Decimal	Binary	Binary Coded Decimal	Excess 3 System
8	1000	1000	1011
+ 3	0011	0011	0110
11	1011	1011	0001 0001
		0001 0001 (a.)	0011 (b.)
			0100 0100

a. The process of converting a binary sum exceeding 9 to

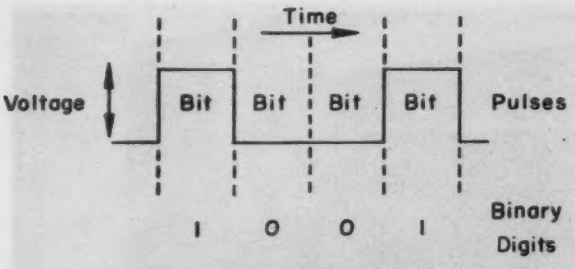


Figure 7. Binary Coded Decimal 9.

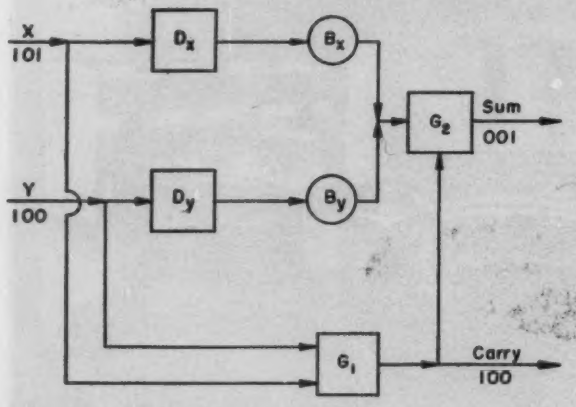


Figure 8. A Half Adder, one of the basic arithmetic circuits in digital computers.

binary coded decimal is sometimes called rationalizing.

b. In the UNIVAC excess 3 systems, if carry occurs, an excess 3 must be added to obtain the correct sum as in the example above; if no carry occurs, an excess 3 must be subtracted (complement 1101 added). It will be noted that a carry in the decimal system will also produce a carry in the excess 3 system.

Subtraction of binary numbers is handled by obtaining the complement of the subtrahend and then adding to the minuend. In binary excess 3, complements are easy to obtain electronically by substituting 1's for 0's and 0's for 1's, then adding 1.

A binary number can be multiplied by 2 by shifting one digit position to the left:

```
6 x 2  =  12
0110  shift left  =        1100  Binary
                  =  0001  0010  Binary Decimal
```

and intermediate multiplications always made by adding the requisite number of times:

```
   4          0100
 x 3        + 0100
 ---        ------
  12        1000
            + 0100
            ------
            1100  Binary
      0001  0010  Binary Decimal
```

Or a binary number can be divided by 2 by shifting one digit position to the right:

```
14 ÷ 2 = 7
1110 shift right = 0111
```

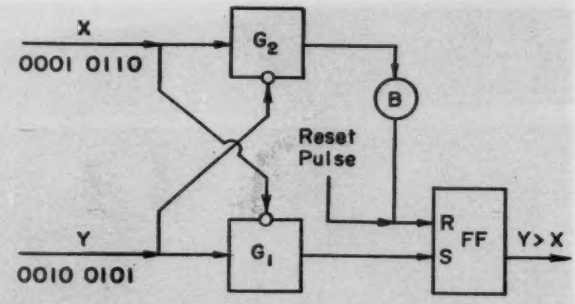


Figure 9. The magnitude comparator, a circuit of gates and flip-flop.

The inherent simplicity of digital arithmetic leads directly to electronic arithmetic[8] through:

a. Handling addition, subtraction, multiplication and division as basically adding, complementing, or shifting the digits, and

b. Reducing all data to a sequence of voltage pulses which are dual choice in nature, as in Figure 7.

Electronic Arithmetic

As addition is the basic operation of a universal computer, electronic arithmetic will be illustrated by the diagrammatic functioning of a Half Adder[9], Figure 8; reference to Computer Terms may be helpful here.

To add 5 (binary 101) and 4 (binary 100), we start from the least significant digit which is on the right as in decimal arithmetic. In the *first pulse time*, a voltage pulse appears on line X and no pulse on line Y. Gate G_1 receives only one input signal, Pulse X, so it decides not to open and therefore not to inhibit Gate G_2. Meanwhile Pulse X passes through Delay D_x which delays it just long enough for the inhibition voltage on Gate G_2, if any, to be energized. Next Pulse X passes through Buffer B_x, meets no opposition from Buffer B_y, passes uninhibited through Gate G_2, and comes out as the Sum Pulse 1. In the *second pulse time*, no input pulse enters either line X or Y so the output is Sum 0. In the *third pulse time*, input pulses appear on both line X and line Y. Now Gate G_1 receives two input signals, Pulses X and Y, so it decides to inhibit Gate G_2. Therefore, Pulse X and Y are prevented from passing Gate G_2, and we have another Sum 0. At the same time, two inputs decides Gate G_1 to pass a signal which is Carry Pulse 1. The answer is then 1001 (decimal 9). For triple input conditions when a carry pulse meets two incoming pulses, a second Half Adder is needed for full binary addition, hence the name. The Half Adder serves also as a Complementer (see definition) and thereby subtracts.

An example of a circuit which makes a decision is the Magnitude Comparator, Figure 9. To compare:

16 = 0001 0110 binary coded decimal on X line.
25 = 0010 0101 binary coded decimal on Y line.

Refer to the figure and begin the comparison at the right with the least significant digit. At the *first pulse time*, Pulse Y on line Y inhibits Gate G_2, but passes through Gate G_1 to put Flip-flop FF on Set S; at this

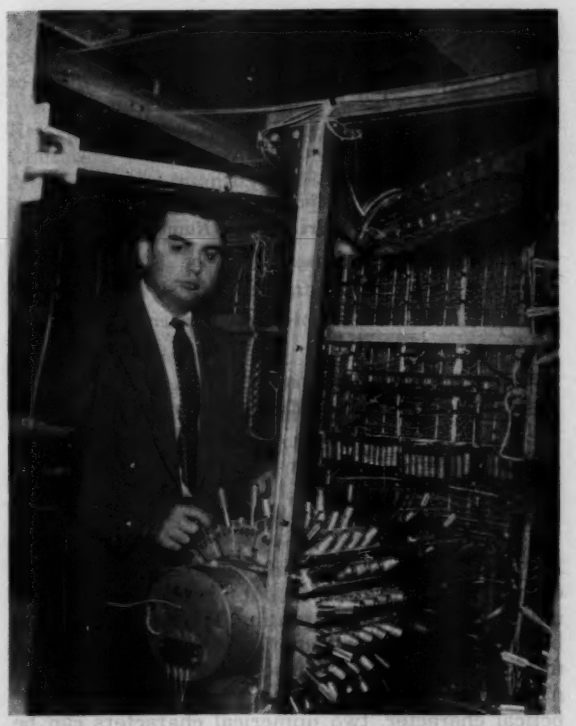


Figure 10. Inside UNIVAC, adjustments are made on one of the acoustic delay main memory units.

stage Y is greater than X. At the *second pulse time,* Pulse X on line X inhibits Gate G_1 but passes through Gate G_2 to restore Flip-flop FF to Restore R; at this stage X is greater than Y. At the *third pulse time,* both X and Y are pulsed and both gates are inhibited; no change in FF. At the *fourth pulse time,* neither X nor Y is pulsed; no change in FF. At the *fifth pulse time,* Pulse X keeps FF on Restore R and X is still greater than Y. At the *sixth pulse time,* Pulse Y inhibits G_2 but passes through G_1 to set FF to S; therefore Y is greater than X (25 greater than 16). Decisions of this kind permit the machine to continue a program without human intervention.

Figure 11. NORC Main Memory, courtesy IBM. General view of the cathode ray tube storage which is located on the back of the NORC main frame.

All of these steps just to add 5 and 4, or to compare 16 and 25 would seem rather cumbersome were it not that the electronic computers are very good at arithmetic and a million such steps are taken every second. Humans cannot inject input data and instructions at such speed, so that many of these must be prestored in "memory."

Internal Memory

One of the most fascinating and enviable facilities of general purpose computers is their prodigious and accurate memory.[10] This form of internal memory, excluding flip-flops, registers and delays, will be examined as to method of storage, capacity, and accessibility using UNIVAC I, NORC and LARC as illustrations.

The method of storing the main internal memory in UNIVAC I is by acoustic delay lines, Figure 10. Advantage is taken of the much slower rate of acoustic propagation compared to electrical propagation. Pulses are transmitted from a transducing crystal through mercury to a receiving crystal. UNIVAC I has 100 mercury memory channels, each storing 10 computer words, and each word containing 84 bits or pulses as will be explained in the next section. The entire storage in acoustic memory is automatically checked every 5 seconds to insure continued correctness. Transfer of data to any of the 000 to 999 word locations automatically erases the information previously stored, but reading from memory leaves the contents undisturbed.

The IBM Naval Ordnance Research Calculator[3] has a quite different design of main memory unit, based on an idea by Professor F. C. Williams of the University of Manchester, England. Here electron beams bombard the inside face of cathode ray storage tubes, analogous to television. The picture in this case is a distinct geometrical matrix of electrostatic information in the form of a dot or dash, each representing 0 and 1 respectively in the binary coded decimal system already described, and each a function of the relative bombardment time. A visual pattern is only for the use of the engineer, as read-out is accomplished by a conducting surface across the outside face of the tube. As phosphor is an insulator, the small charges on the inside screen would remain a few seconds like a radar scope but, to overcome fading, the pattern is repeatedly refreshed. A NORC word has 66 bits or pulses. NORC main memory, or random-access storage, Figure 11, has a capacity for from 2000 to 3600 such words, depending upon the desired packing of the dots and dashes on the face of the tubes. As to accessibility, arrangement of the storage tubes in parallel makes it possible to record a word in storage, to read out a complete word, or to refresh the tube patterns in any 8-microsecond interval. As an example of scheduling accessibility during the 8-microsecond interval:

Microsecond	Operations
1, 2, 3, 4	Position the beams concurrently in each of 66 tubes to read concurrently the 66 pulses that make up a NORC word.
5	Beam reads out previously stored pulse.
6, 7, 8	Beam restores previous information fully regenerated and refreshed, or reads in new information.

Refreshment occurs automatically if storage of new information is not demanded.

LARC main memory is stored in magnetic ferrite cores[11]. Electromagnetic memory is completely passive as compared to acoustic mercury delay or electronic phosphor screen, and has an advantage that no recycling is necessary. Information is stored in a binary manner as in other units. Square hysteresis loop ferrite circuits also have the ability to count digitally then store the count. The basic main memory in the LARC ordered by the Bureau of Ships will store 20,000 words, each comprising 60 bits of digital information. The basic pulse time, or time-slot, for LARC is ½ microsecond. The complete main memory cycle is 4 microseconds, 2 microseconds for reading out a word followed by 2 microseconds for storing or regenerating a word.

Pulse Wording

In describing internal main memory, the capacities of the representative computers have been measured as:

Computer	Words	Pulses Per Word
UNIVAC	1,000	84
NORC	3,600	66
LARC	20,000 to 97,500	60

What, then, are the word structures for each of these computers?

We have seen that any binary information can be represented by a single pulse, and that any decimal digit can be transmitted by a series of 4 pulses. In the same manner, series of pulses can represent signs, symbols, letters, punctuation, operations and instructions.

Groups of related pulses form a character. In UNIVAC, each character has 7 pulse positions or bits of information. Reading from the bottom, or least significant digit, the first 4 pulses form the binary equivalent of a decimal digit. The next 2 pulse positions are the zone indicators, coded to designate an instruction,

One UNIVAC Character

X — Check Pulse
X, X — Zone Indicator
X, X, X, X — Binary

an alphabetic character, punctuation, or printer operation for the meaning represented in the 4 binary pulse positions. Finally, the check pulse is used to detect the gain or loss of a binary pulse and is automatically added as necessary to make the number of pulses in a character odd. For examples:

UNIVAC Numerical Character

1 — To Make Odd Number Pulses
0, 0 — Zone Numerical
1, 0, 0, 1 — Decimal 6 in Excess 3 System

UNIVAC Punctuation Character

0 — Already Odd Number Pulses
0, 1 — Zone Punctuation
0, 0, 1, 1 — Semi-Colon (Numerical Part)

UNIVAC Alphabetical Character

1 — To Make Odd Number Pulses
1, 1 — Zone Alphabetical
1, 0, 0, 1 — Letter W (Numerical Part)

In NORC, designed primarily for scientific problems, each character has only 4 pulse positions for maximum efficiency in representing decimal digits in the binary coded decimal notation. In LARC, each numerical character has 5 pulse positions, 4 binary decimal digits and a check pulse; to represent an alphabetical character, two numerical characters can be combined.

Groups of related characters form a word. UNIVAC words are made up of 12 characters, which may represent a numerical quantity consisting of an algebraic sign followed by 11 decimal digits:

UNIVAC Numerical Word

0 — Algebraic Sign
0, 0, 2, 9, 7, 4, 3, 1, 6, 5, 4 — Mantissa

Unless programmed otherwise, UNIVAC uses a fixed decimal point location, immediately to the right of the algebraic sign. Here 0 represents a plus sign. A UNIVAC word may also represent two instructions to the computer, each composed of 6 characters:

UNIVAC Instruction Word

S, 0 — Operation
0 — Not Decoded
3, 2, 1 — Memory Location
T, 0 — Operations
0 — Not Decoded
5, 4, 6 — Memory Location

In the first instruction, Operation S directs transfer of minus the quantity in Memory Location 321 to Register X, add the quantity in Register X to the quantity in Register A, and deliver the result to Register A. In the second instruction in this word, Operation T directs that, if the quantity in Register A exceeds the quantity in Register L, the next instruction shall be obtained from Memory Location 546.

NORC words are made up of 17 characters, and likewise have both the number and instruction type of words:

NORC Numerical Word

2	Check
1, 2	Decimal Index
0	Algebraic Sign
0, 0, 2, 9, 7, 4, 3, 1, 6, 8, 5, 3, 7	Mantissa

Check 2 is a measure of the number of pulses in this word to the nearest multiple of 4 pulses plus 3, so that if a loss or gain occurs it will be detected. Decimal index 12 denotes a decimal position 12 places to the right of the home position which, in NORC, always follows the first digit after the algebraic sign. This system is called a floating decimal point. Word structure to give instructions are of the form:

NORC Instruction Word

1	Check
0, 7	Operation
2, 4	Operation
0, 5, 2, 8	Memory Location
0, 1, 3, 6	Memory Location
0, 6, 7, 4	Memory Location

Check 1 is a measure of the pulse count. Operations 07 and 24 direct the machine to take the quantity in Memory Location 528, multiply it by the quantity in Memory Location 136, round the answer to 5 decimal places, and store the result in Memory Location 674. NORC is an example of a three-address instruction.

LARC computer words will be composed of 12 characters. Numerical words will have an algebraic sign followed by 11 decimal digits as in UNIVAC, and with either fixed or floating decimal location. Instruction words will be made up of:

LARC Instruction Word

X, X, X	Operation
X, X	A Register Address
X, X	B Register Address
X, X, X, X, X, X, X	Main Memory Location

Flow of these instructions will be discussed under the more detailed description of LARC to follow.

Pulse wording therefore provides the means to issue orders and instructions to the computers to perform various step operations. From less than 100 basic instructions, complex series and combinations of operations can be specified permitting highly versatile numerical calculations. The planning of these operations leads to computer logic and programming.

Computer Logic

In devising a computer solution for an engineering or logistic problem, the principal steps are:

Problem Analysis
Programming
Coding
Operating Instructions
Problem Run

Problem analysis requires mature mathematical ability and a clear understanding of the solution sought. Programming describes the procedure that a universal computer can follow to solve a particular problem, and is most often expressed in the form of a flow chart. Coding reduces the programmed procedure to specific instructions capable of making the specific computer perform the desired calculations. Operating instructions set forth clearly all the information that the computer operator needs to run the problem. Problem run involves the transfer of the written instructions to the input media such as tape, operation of the machine through a sample run, and careful checking at each stage.

The logical operations, which are combined in a program to solve a particular problem, fall generally into three groups:

Transfer
Counting
Choice

Transfer instructions provide for the shift of information from one memory location to another, for directives to erase, clear or ignore, and for the selection, assembly and deletion of information. Counting embraces all of the basic numerical operations. Choice instructions are typified by shifts of control

if one number is greater than, equal to, or less than another, by start or stop direction, by selection on the basis of algebraic sign or other characteristic of a number, and by the overflow of numbers as the result of arithmetical manipulations.

If the various logical operations are represented graphically, a flow chart provides a useful means for organization, analysis and improvement of the program. Layout sheets for key computer words are another aid in analysis, programming, coding and editing. For large and complex problems, preliminary diagramming of the broad operations is valuable prior to flow charting the detailed technical steps. Examples of both layout sheets and flow diagrams are given under Logistic Problems. Finally the flow charts are translated into explicit instructions in the computer code.

Routines and sub-routines are likewise tools of programmers. Some of the building blocks can often be canned routines, which have been logically coded and progressively purified to reduce machine time. A library of sub-routines for repetitive operations encountered in naval engineering problems is being generated at the David Taylor Model Basin.

Automatic routines are pseudo-codes to bridge the gap between steps to be followed for a given problem, and the final coding of that problem for a particular machine. They are classed generally as:

Interpretive
Generative
Compiling

Interpretive routines translate into machine code as well as refer to stored sub-routines and execute them in the course of computation. Generators will produce a routine to perform a desired operation. Compiling draws on generated or library sub-routines, organizes them, and can produce a complete program. In some highly complex analyses, automatic programming has become inescapable to make the problem feasible. For example in an automatic program called FRAMEWORK:

(Instructions for generating input, output and rerun for any routine)

PLUS

(Parameters and own code for particular routine)

EQUALS

(Generated routine, including input, output and rerun)

Research is underway to utilize UNIVAC for developing automatic routines for LARC.

The LARC

To illustrate computer capabilities that will become available in 1958, features of LARC will be described more fully. Purchase specifications to which Remington Rand is building the Large Automatic Research Calculators[4], as well as many subtleties of the design, reflect the needs of the Atomic

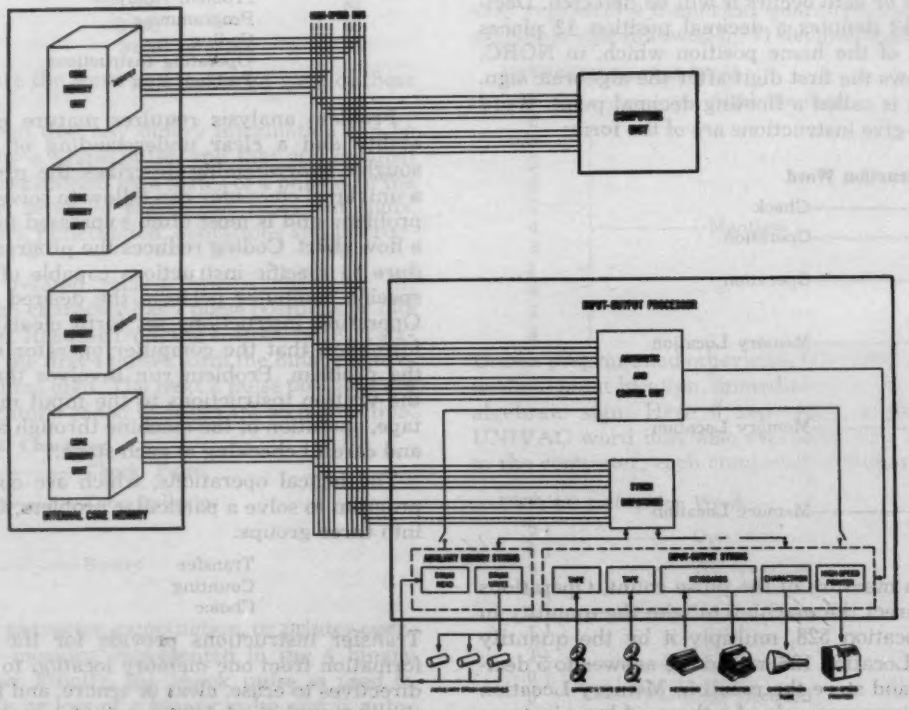


Figure 12. The LARC Computing System. A high-speed bus links the internal core memory, computing units, and processor; the latter controls input from and output to drum memory, tape servos, keyboards, character tube, and high-speed printer.

Energy Commission and the Bureau of Ships. The particular LARC for the David Taylor Model Basin is sometimes referred to as the SHARC, or Ships Automatic Research Calculator.

LARC will be a two-headed system. One computer, called a processor, will have primary control over the input-output equipment and the other, called the main computing unit, will be served by the processor, Figure 12. Processor and computing unit will share main memory on an interleaved time-slot arrangement, with the processor having priority if need be. The anticipated versatility and capacity of LARC will be due principally to developments in logical design, to improvements in circuitry, and to overlapping operations.

Essentially, a three-level memory system is planned. The most accessible information will be the high-speed registers with a complete memory cycle time of 1 microsecond. These registers store the factors being used and avoid unnecessary return to main memory. At the next level, high-speed magnetic core memory will have a 4-microsecond complete cycle for reading and writing or regenerating. Finally, a high-capacity drum file memory system will be employed; they will be in effect large economical warehouses where information is reasonably accessible for distribution. With good programming[12], drum files should be readable in low latency time.

The A-registers both do arithmetic and serve as accumulators for storing operands and operational results. The B-register function, to modify instructions during actual operation, will be highly exploited. In any general purpose computer, it is possible to program a sequence of instructions to be carried out over and over again, each time using a different set of operands, but LARC will have an exceptional degree of built-in automation for these iterative loops. The Bureau of Ships LARC package contemplates 66 interchangeable one-word A and B-registers. In addition, 4 control-counter registers to keep track of the last, present, next, and next after next instruction to the machine, and 3 instruction registers to control 3 overlapping operations complete the family of registers.

The main memory units will each store 2500 words in coincident current ferrite cores. Arranged modularly, 4 complete memory units are in each memory cabinet, and the Bureau of Ships package as presently planned will contain 2 such cabinets, total capacity 20,000 words. Each memory unit will furnish simultaneously 60 bits of binary information (12 LARC characters) over 60 parallel connections. Main memory will be expansible up to 97,500 words (2500 word block reserved for special register addresses). Therefore, main memory addresses have 5-digit decimals, 00000 to 20,000 for DTMB LARC. The time interval between successive read outs or ins from main memory is ½ microsecond. Memory information likewise is furnished or received on any computer ½ microsecond time slot allotted on the high speed bus. A complete memory cycle requires 4 microseconds.

Figure 13. One of the LARC 2-foot drums 30 inches long for storage of magnetic memory, under construction at Remington Rand. Drum motion at 860 RPM develops an entrained boundary layer which aerodynamically lifts the magnetic reading and writing head against spring pressure; the head skis along on the windage with a clearance above the drum surface in the order of 0.0001 inch despite slight out-of-roundness of the drum.

If processor or computing unit finds the memory unit engaged, as indicated by a guard flip-flop, appeal to memory will be made again on the next cycle. Instructions and operands are stored in separate modular memory units, so that the computing unit can obtain them simultaneously rather than sequentially. At the same time, the processor can be filling a third memory unit from an input source, and reading from a fourth memory unit onto an output device. Each core memory unit is therefore a logical entity.

Supplementing magnetic tape input and output, drum files will be used in LARC for economical supporting memory. The drums will be plated with a magnetic alloy, and data recorded in 100 bands on each drum. The magnetic head for reading and writing will be air floated from the drum surface, Figure 13, which will permit pulse densities of 400 bits to the inch. Continuous readings are obtained during head indexing by interlacing the timing of 2 or more drums. In the 12 drums of the DTMB LARC, it will be possible to store 3,000,000 words containing 36,000,000 decimal digits containing 180,000,000 pulse positions. Information transferred from drums enters the system via the main core memory and leaves by the same route.

The processor is a general purpose stored-program computer, specialized in the parallel control of input and output equipment. The flow of words between magnetic drums and tapes and the processor is controlled by synchronizers, which permit as many as 8 inputs or outputs to occur simultaneously. The processor will, in effect, be a respected servant to the computing unit. The computing unit will ask the availability of the processor before requesting input or output. If the computing unit finds that the proces-

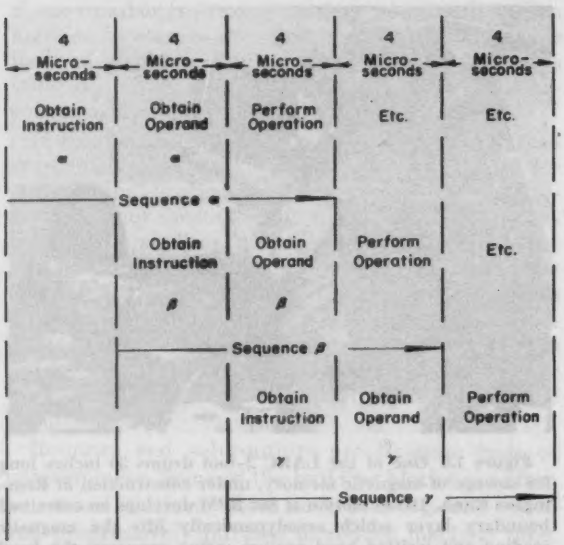


Figure 14. Overlapping sequences reduce the effective time for a complete operation, such as a multiplication, from 12 to 4 microseconds.

sor is busy, it will return to calculating some other phase of the problem and come back later. Precedence for the processor is necessary because of the lower accessibility of input-output equipment and information. It is possible for processor and computing unit each to go its calculating way independently for the most part, so that each computer can work at its maximum inherent speed. The processor should be particularly useful for input-output sub-routines.

The computing unit specializes in high speed arithmetic and mathematical logic. For example, the adder will receive two 12-digit numbers in parallel and produce a 12-digit sum as output in 1 microsecond. Three separate instruction registers permit the concurrent computation of three staggered operations. A normal sequence includes:

a. Obtain instruction from the main core memory.
b. Modification of the instruction address by an index register.
c. Obtain the operand from the modified address.
d. Calculation using an arithmetic register.
e. Check during the above sequence.

The total elapsed time is 12 microseconds for all 5 steps in a multiplication. By parallel operation, steps a, c and d are going on concurrently for each of 3 instructions which triples the speed of calculation, Figure 14. The computing unit handles single or double precision operations with, as explained under pulse wording, either fixed or floating decimal

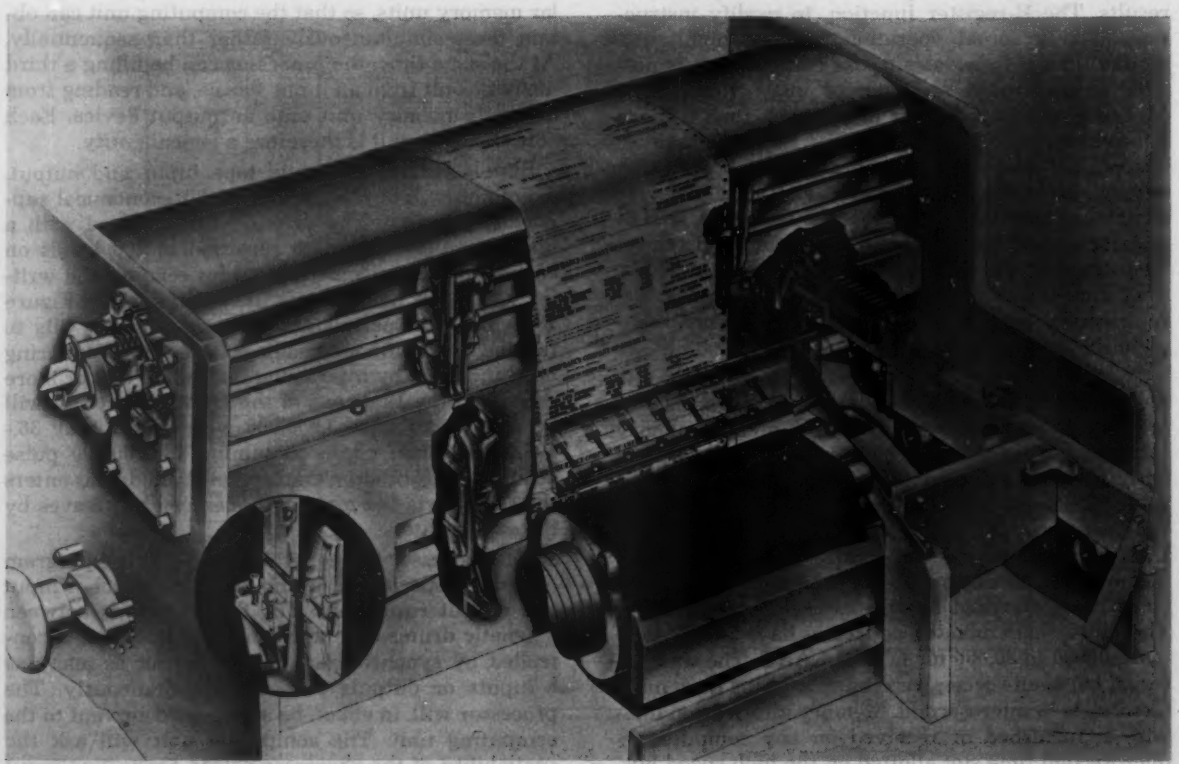


Figure 15. UNIVAC High Speed Printer, cutaway view. A choice of 51 different characters can be printed from magnetic tapes in lines of 120 characters each at a rate of 600 lines per minute.

Figure 16. Automatic plotter developed by the David Taylor Model Basin in collaboration with Benson-Lehner Corporation. Output data on magnetic tapes are plotted directly, a technique highly useful in mapping calculated flux contours in reactors.

points. Automatic transfer to an error routine occurs in case of machine error or an untenable situation. The computing unit or processor can be used to diagnose the troubles of each other. The LARC system can be expanded to include a second computing unit, to be served by the same processor.

The high-speed bus links the system as shown in Figure 12. The basic 4-microsecond cycle of the high-speed bus is divided into 8 time slots which are assigned to different units of the machine. Any single transfer of information to or from core memory occupies the high-speed bus for only ½ microsecond. Words are transmitted completely in parallel.

In the output equipment area, a high-speed printer will be controlled and fed by the processor, printing up to 120 characters per line at a rate of 1200 lines per minute, equivalent to 2,400 characters per second. A printing rate double that of the present printer, Figure 15, is obtained by eliminating alphabetical characters in favor of numerical output in which LARC specializes. The highly successful automatic plotter, Figure 16, developed for output of neutron flux patterns, will continue to serve. It is possible that a peak rate of 25,000 characters per second can be obtained with a charactron tube used as a high speed printing device.

LARC will have both an Operator's Console and an Engineer's Console. The operator will have controls for stopping and starting a program, transfer operations, mode of operation of the computers, and various manual interventions. He will have a keyboard for manual entry and a program-controlled printer for monitoring. The engineer will have controls for locating and diagnosing malfunctioning of any of the computing, memory, or input-output equipment.

Over 90 per cent of the operational failures in computers occur in tubes. The wide use of transmitters and ferrite cores in LARC will reduce the number of tubes to about 100, whereas over 20,000 tubes would have been required if UNIVAC-type circuits had been employed. Both reliability and speed of operation should be much enhanced.

III. NAVAL APPLICATIONS

Perhaps the most direct means of conveying the recent growth and present scope of computer mathematics in naval engineering is to denote specific problems that have been and can be handled[13].

Such an outline has the further and immediate advantage of making known for the information of the American Society of Naval Engineers UNIVAC codes available in the program library of the Applied Mathematics Library. Many of these codes are used regularly by activities associated with the Bureau of Ships, and this library is already a valuable part of the DTMB naval computing service. This service is available on Bureau of Ships contracts.

Some of the activities served, other than the Bureau of Ships and the laboratories of the David Taylor Model Basin, are:

Knolls Atomic Power Laboratory
Oak Ridge National Laboratory
Engineering and Research Corporation
National Science Foundation
Combustion Engineering Corporation
Applied Physics Laboratory
Westinghouse Atomic Power Division
Naval Engineering Experiment Station
New York Naval Shipyard
Naval Postgraduate School
Navy Underwater Sound Laboratory
Puget Sound Naval Shipyard
Naval Radiological Defense Laboratory
Norfolk Naval Shipyard
Joint Chiefs of Staff
Office of Defense Mobilization
Aeronautical Radio, Incorporated
Naval Gun Factory
Mine Defense Laboratory
Ships Parts Control Center, Mechanicsburg

Engineering Problems

Examples of original engineering problems undertaken[14] are calculation of:

a. Mutual impedance between two adjacent whip antennas aboard a submarine operating at periscope depth.

b. Natural frequencies and normal modes of vibration of a rigid assembly resiliently mounted with respect to arbitrarily oriented axes.

c. Intervals of time, calculated from Haldane's tissue pressure formulas, that an ascending diver is required to wait at various depths in order to avoid decompression sickness, including the effect of previous dives.

d. Buckling of stiffened circular and nearly circular cylindrical shells subjected to external hydrostatic pressure, Figure 17.

Figure 17. The model submarine hull in the photograph has been subjected to external pressure until it collapsed by instability, as indicated by the diamond pattern of failure. Structural behavior of this kind is now programmed and computed routinely.

e. Radioactive fall-out for hypothetical patterns of attack, weapon yields, and wind conditions at designated areas in the United States.

f. Equations of motion for emergency control of a damaged submarine.

g. Wind tunnel data to determine bending moments in wing surface under widely varying conditions.

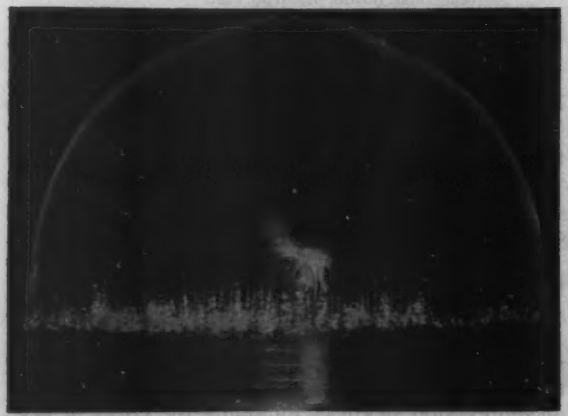


Figure 18. Boundary layer mechanics and inception of cavitation around submerged forms can now be machine-calculated for many shapes, such as this body of revolution in the variable-pressure water tunnel at the California Institute of Technology.

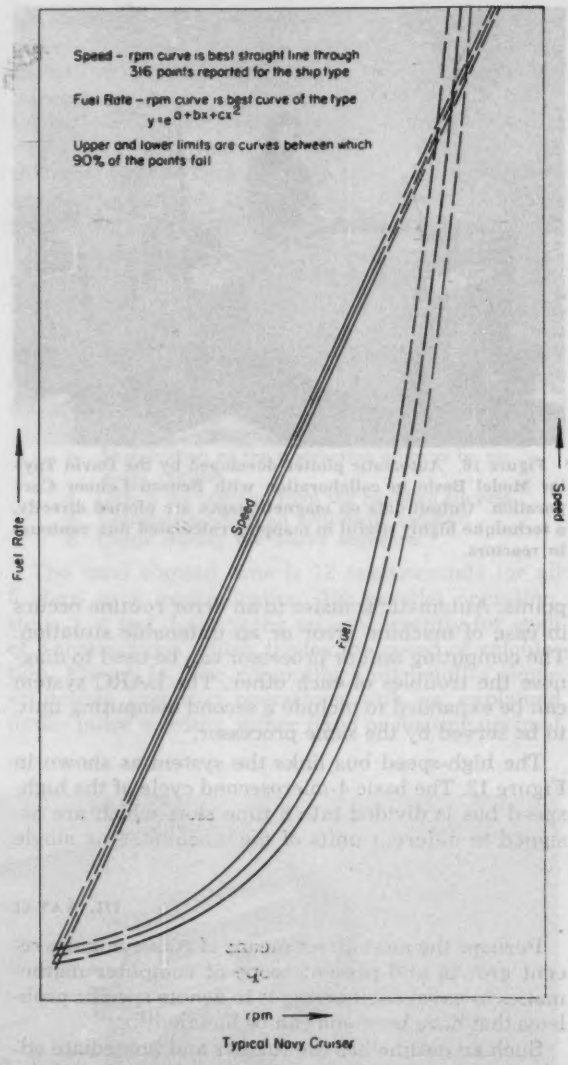

Speed – rpm curve is best straight line through 316 points reported for the ship type
Fuel Rate – rpm curve is best curve of the type $y = e^{a+bx+cx^2}$
Upper and lower limits are curves between which 90% of the points fall
Fuel Rate
Speed
Speed
Fuel
rpm
Typical Navy Cruiser

Figure 19. Curves are fitted by computer to voluminous fuel rate data for ships of the U. S. Navy operated under a wide range of conditions.

h. Critical frequencies, from 39 simultaneous equations, and corresponding modes of torsional vibration of a planetary gear propulsion system.

i. Sound propagation in surface sound channels for a large number of acoustic frequencies, varying depths of projector and receiver, and extended horizontal ranges.

j. Determination of the boundary layer development, inception of cavitation and variation of resistance with speed for a systematic series of bodies of revolution, Figure 18.

k. Power spectrum analysis of ocean wave records, and of ship model motions in irregular seas.

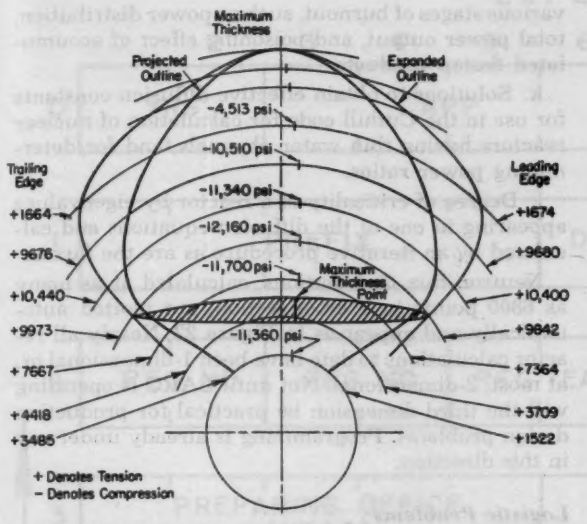


Figure 20. Nominal Stresses in a Propeller as calculated by UNIVAC. With propeller design shape and parameter as input, the program produces for each blade section the area, center of gravity, moments of inertia, bending moments, and stresses at the maximum thickness and at the leading and trailing edges.

l. Pressure distribution on a family of propeller shaft struts.

m. Natural whirling frequencies and associated modes for the rotating propeller shafts of new aircraft carriers.

n. Large elastic bending of heavy tapered cantilevers with hydrodynamic loading.

o. Response of a MARINER hull to a simple harmonic driving force.

p. Equilibrium configuration of a flexible cable in a uniform stream.

q. Curve fitting of hourly underway service fuel rates for 696 ships of the U. S. Fleet, Figure 19.

r. Horizontal, vertical and torsional bending modes for 34 ships of the U. S. Fleet.

s. Analysis of factors affecting bearing performance.

t. Coupled bending-torsion modes of vibration in a ship's hull.[15]

u. Dynamic stability of submarines from analysis of full scale trials.

v. Stress distributions in full scale propeller blades with various sections and loadings predicted from model tests, Figure 20.

Routine calculations, once programmed and coded, can put engineering money in the bank every day. In the Surface Ships Powering Section of the DTMB Hydromechanics Laboratory, the effective working force has been increased from 21 to 27 people without actual increase in personnel, simply by routinizing model data reduction and extrapolation procedures for UNIVAC. A complete EHP prediction by the Schoenherr line with roughness allowances, which formerly required 1½ days of desk calculation, is now done with 20 minutes for data preparation and 2 minutes of computer time. Comparable economies are made in SHP, propeller, and other model predictions, all with increased accuracy of the final products. Automation for engineers is a most significant means in which the availability of professional personnel has been increased, and in which laboratory service to ship designers has been augmented.

Reactor Calculations

By far the preponderance of naval computer time has been devoted to calculations for the Chief of the Naval Reactor Branch, Atomic Energy Commission, and Assistant Chief of the Bureau of Ships for Nuclear Propulsion. So little operating experience has been obtained as yet in this new field of naval engineering that most design explorations are, of necessity, made through the collaboration of the engineer, physicist and mathematician. Over 200 different reactor models have been simulated and explored by calculations at the Taylor Model Basin.

The mathematics of nuclear reactors is based on the conservation of neutrons, and the general equation is:

Change of Neutron Density =
Production — Leakage — Absorption

Now the fundamental expression is the Boltzmann Transport Theory, similar to that used in his studies of gas diffusion[16]; it is difficult to handle but necessary for anisotropic scattering or sources[17]. However, if it can be assumed that the energy and the angular distribution of neutron velocity vectors are isotropic, the simpler Diffusion Theory is satisfactory. A comparison of the two theories is given in Figure 21. The Monte Carlo Theory aims to simulate a reactor by actually following the paths of each neutron and keeping a record of its physical state[18]; it is the simplest mathematical approach but for 1- and 2-dimen-

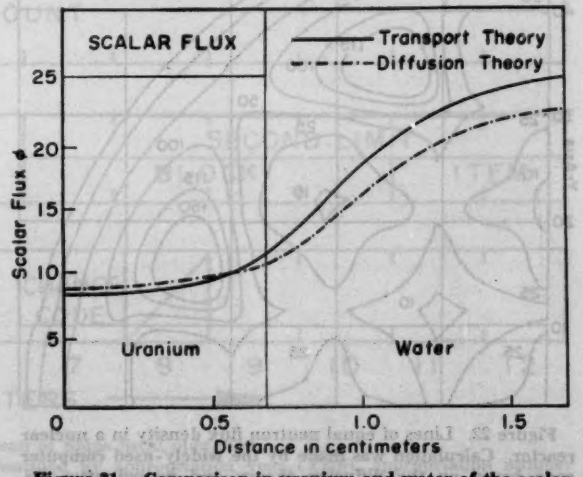


Figure 21. Comparison in uranium and water of the scalar flux in a reactor as predicted by the transport and diffusion theories.

sional codes involves excessive machine time. Computer codes to simulate reactor designs have been developed for UNIVAC, NORC and IBM 704.

Examples of reactor calculations already undertaken[14] are:

a. Penetration of neutrons and gamma rays in a shield composed of alternate layers of iron and water.

b. Reactor temperatures and pressures in the SEAWOLF submarine intermediate reactor following various transients in throttle openings.

c. Doppler broadening correction for neutron resonances.

d. Criticality in a reactor as calculated by two coupled Helmholtz equations.

e. Comparison between the integral network method of calculating radiation penetration in an infinite homogeneous medium and the previously established moments method.

f. Calculation of the average power ratio; that is, the space average of the scalar neutron flux in a specified region of a reactor cell and the subsequent evaluation of the ratio of this average to the flux at a pre-assigned interface.

g. Thermal neutron calculations for a uranium-water reactor cell based on approximations leading to the diffusion equation, and more rigorous mathematical treatment based on solution of the integral transport equation.

h. Derivation of a direct integration method for solution of the 1-dimensional Boltzmann transport equation.

i. Determination of optimum lattice spacing and angular divisions.

j. Approximate predictions of reactor behavior at various stages of burnout, such as power distribution, total power output, and poisoning effect of accumulated fission products.

k. Solutions to obtain effective diffusion constants for use in the Cuthill code for calculation of nuclear reactors having thin water channels, and for determining power ratios.

l. Degree of criticality of a reactor by eigenvalues appearing in one of the diffusion equations and calculated by an iterative procedure as are the fluxes.

Neutron flux distributions, calculated at as many as 6800 points in a cross-section, are plotted automatically and appear as in Figure 22. Nearly all reactor calculations to date have been 1-dimensional or, at most, 2-dimensional. Not until LARC is operating will the third dimension be practical for production design problems. Programming is already underway in this direction.

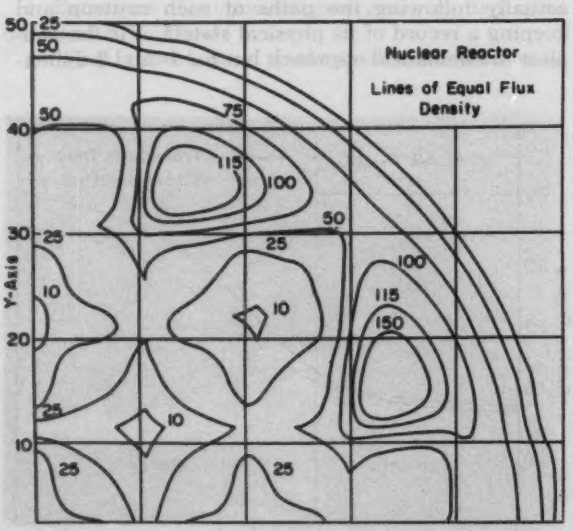


Figure 22. Lines of equal neutron flux density in a nuclear reactor. Calculation was made by the widely-used computer code based on the diffusion theory and named after Dr. Elizabeth Cuthill of the Applied Mathematics Laboratory, and the results were automatically plotted.

Logistic Problems

Whereas engineering applications have positively established their economy, logistic problems in many cases have proved more difficult to program and direct returns have not been so readily apparent. Nevertheless, several convincing performances have already been registered.

An urgent major task of the logistic variety developed immediately after the first UNIVAC was in operation at the Applied Mathematics Laboratory. Public Law 239, passed by the 83rd Congress in 1953, provided important survivor's benefits for personnel of the three Armed Services. To implement the law on time required that 122 tables comprising about 400,000 entries be completely calculated and compiled by 15 October 1953. The problem was defined on 17 September, the required mortality tables were received on 1 October, yet the problem was programmed, coded, computed, checked and printed before the 15 October deadline.[19] By having a mathematics laboratory, the Navy saved $150,000, together with months of calculating time, and was able to enhance morale throughout the Services by the prompt assist in this highly personal benefit law.

Other logistics problems for which valuable calculations have been made are:

a. Analysis of failure rates of electronic equipment at Naval installations and aboard ship; one of the reports produced summarize all failures of each tube within each circuit of every piece of equipment, and is issued as a "report by exception" to reduce its volume materially.

b. Preparation of a material requirements report giving the amount of each material needed each month for a given shipbuilding program phased over a 3-year construction period[20,21].

c. Payroll for 1200 men for a 2-week period, including shifts in personnel, allowances for overtime and vacations, changes in salaries, and deductions for retirement and bonds, completed on UNIVAC in 6 minutes.

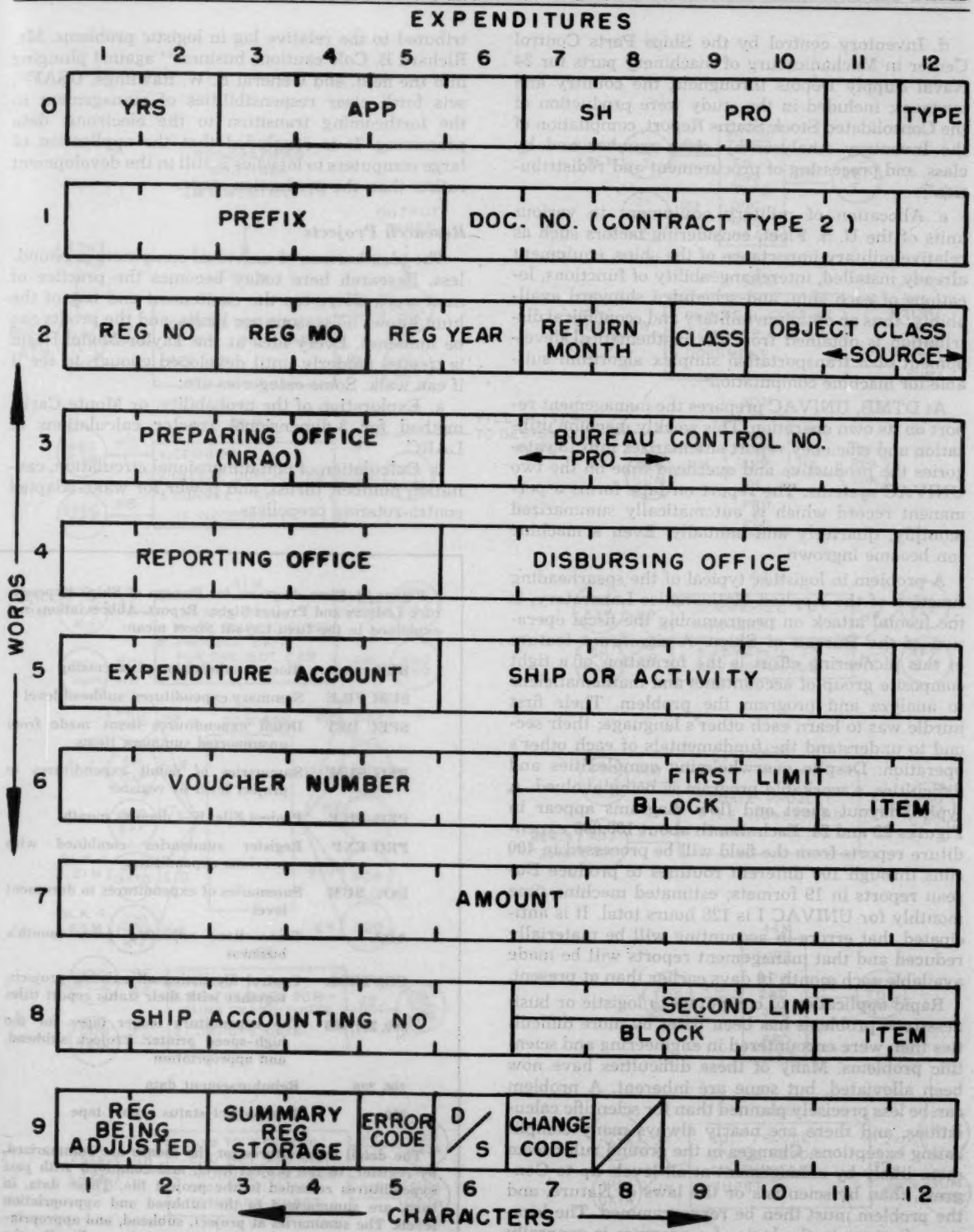


Figure 23. An Item Layout Sheet for programming the Bureau of Ships fiscal operation.
The basic accounting level is the document. A document is identified by appropriation year (YRS), appropriation number (APP), subhead number (SH), project number (PRO), type and document number (DOC. NO.). REG MO and REG YEAR designate month or year data were received. In addition to being grouped by document, the expenditures from the Navy Regional Accounts Offices (NRAO) are classified by register (REG), by expenditure account, and by object class. D/S designates an expenditure item as detail or summary.

d. Inventory control by the Ships Parts Control Center in Mechanicsburg of machinery parts for 24 Naval Supply Depots throughout the country and overseas; included in the study were production of the Consolidated Stock Status Report, compilation of the Inventory Analyses by stock number and by class, and processing of procurement and redistribution[22].

e. Allocation of military equipment to various units of the U. S. Fleet, considering factors such as relative military importance of the ships, equipment already installed, interchangeability of functions, locations of each ship, and scheduled shipyard availability; thus an optimum military and economical distribution is obtained from the mathematical development of a transportation simplex algorithm suitable for machine computation[23].

At DTMB, UNIVAC prepares the management report on its own operation. This weekly machine utilization and efficiency report summarizes into 18 categories the productive and overhead time on the two UNIVAC systems. The report on tape forms a permanent record which is automatically summarized monthly, quarterly and annually. Even a machine can become ingrown.

A problem in logistics, typical of the spearheading function of the Applied Mathematics Laboratory, is the frontal attack on programming the fiscal operation of the Bureau of Ships. A significant feature of this pioneering effort is the formation of a tight composite group of accountants and mathematicians to analyze and program the problem. Their first hurdle was to learn each other's language; their second to understand the fundamentals of each other's operation. Despite overwhelming complexities and difficulties, a workable program is being evolved. A typical layout sheet and flow diagrams appear in Figures 23 and 24. Each month about 100,000 expenditure reports from the field will be processed in 400 runs through 100 different routines to produce Bureau reports in 19 formats; estimated machine time monthly for UNIVAC I is 128 hours total. It is anticipated that errors in accounting will be materially reduced and that management reports will be made available each month 10 days earlier than at present.

Rapid application of computers to logistic or business-type problems has been beset by more difficulties than were encountered in engineering and scientific problems. Many of these difficulties have now been alleviated, but some are inherent. A problem can be less precisely planned than for scientific calculations, and there are nearly always many complicating exceptions. Changes in the ground rules seem more likely by management at all levels up to Congress, than by scientists or the laws of Nature, and the problem must then be reprogrammed. The location of errors in the logic of a program is generally more difficult in the business type. Lack of tested logistic techniques, shortage of experienced computer personnel, and natural resistance of employees accustomed to conventional equipment have contributed to the relative lag in logistic problems. Mr. Richard B. Cole cautions business[24] against plunging into the field, and General E. W. Rawlings, USAF[25], sets forth clear responsibilities of management in the forthcoming transition to the electronic data processing. It is concluded that the application of large computers to logistics is still in the development rather than the production stage.

Research Projects

The idea horizon of universal computers is boundless. Research here today becomes the practice of next week. Here too the excitement and bag of the hunt knows no seasons nor limits, and the profits can be immense. Every idea at the Taylor Model Basin is treated tenderly until developed enough to see if if can walk. Some categories are:

a. Exploration of the probability, or Monte Carlo, method for 3-dimensional reactor calculations in LARC.

b. Calculation of non-dimensional circulation, cavitation number, thrust, and power for wake-adapted contra-rotating propellers.

Figure 24. Flow diagrams for Bureau of Ships Expenditure Ledgers and Project Status Report. Abbreviations not explained in the Item Layout Sheet mean:

BLK.	**Block, a subdivision of processing**
SUM FILE	**Summary expenditures, subhead level**
SPEC DET	**Detail expenditures items made from unsupported summary items**
REG SUM	**Summaries of detail expenditures to project level by register**
PRO FILE	**Project File. K-1 denotes month**
PRO EXP	**Register summaries combined with previous expenditures**
DOC SUM	**Summaries of expenditures to document level**
ADJ.	**Transactions adjusting prior month's business**
CONTROL	**Control file listing all existing projects, together with their status report titles**
200, 201, 203	**The expenditure ledger tapes for the high-speed printer. Project, subhead, and appropriation**
206, 220	**Reimbursement data**
300	**The project status report tape**

The detail expenditures for the month are summarized, by register, to the project level, and combined with past expenditures recorded in the project file. These data, in turn, are summarized to the subhead and appropriation levels. The summaries at project, subhead, and appropriation levels produce the expenditure ledgers. Finally, the project file, having been updated, is rearranged into the project status report.

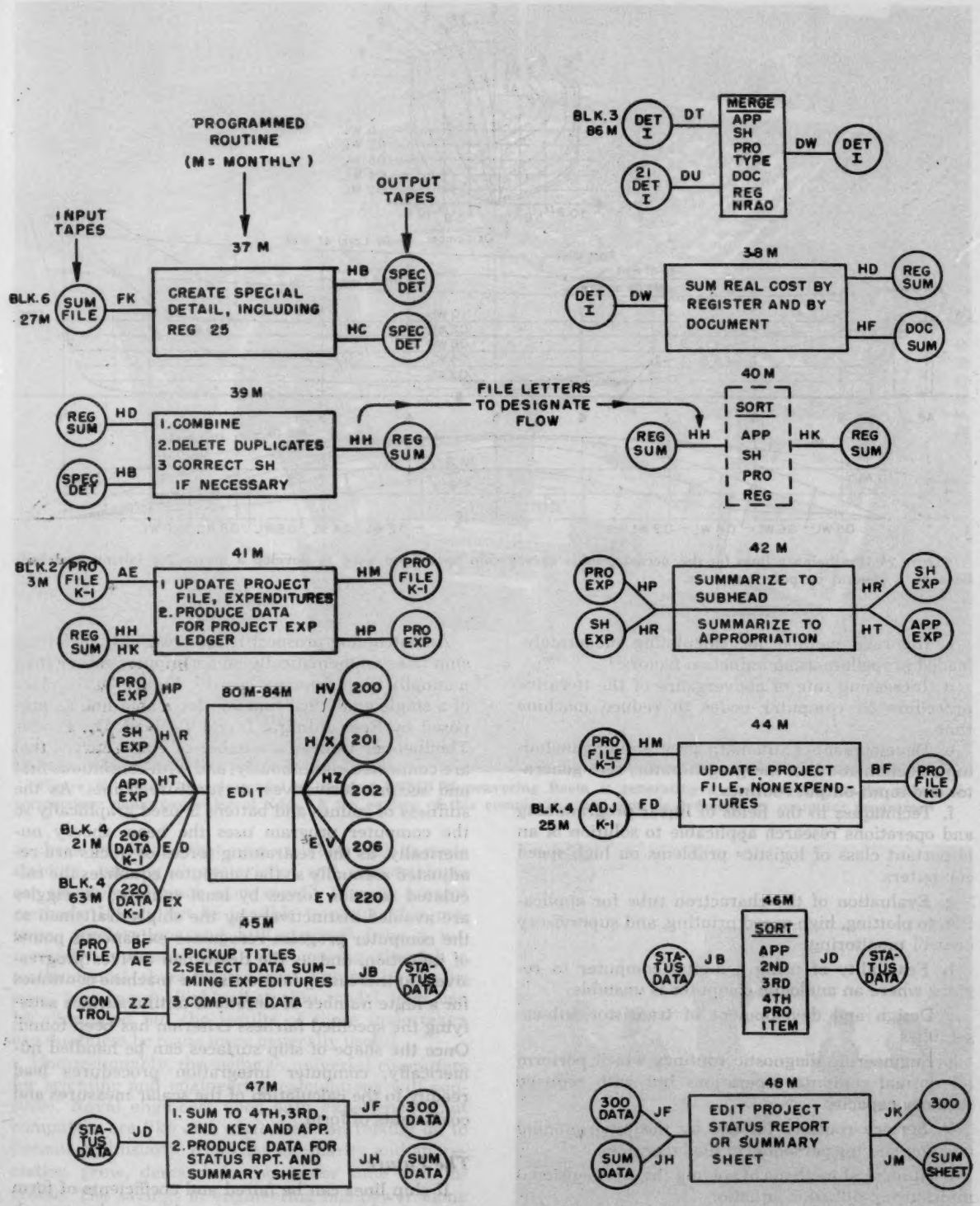

PROGRAMMED ROUTINE
(M = MONTHLY)
INPUT TAPES
OUTPUT TAPES
37 M
BLK. 6 27M
SUM FILE
FK
CREATE SPECIAL DETAIL, INCLUDING REG 25
HB
SPEC DET
HC
SPEC DET
BLK. 3 86 M
DET I
DT
21 DET I
DU
MERGE
APP
SH
PRO
TYPE
DOC
REG
NRAO
DW
DET I
38 M
DET I
DW
SUM REAL COST BY REGISTER AND BY DOCUMENT
HD
REG SUM
HF
DOC SUM
39 M
REG SUM
HD
SPEC DET
HB
1. COMBINE
2. DELETE DUPLICATES
3 CORRECT SH IF NECESSARY
HH
REG SUM
FILE LETTERS TO DESIGNATE FLOW
40 M
REG SUM
HH
SORT
APP
SH
PRO
REG
HK
REG SUM
41 M
BLK. 2 3M
PRO FILE K-1
AE
1 UPDATE PROJECT FILE, EXPENDITURES
2. PRODUCE DATA FOR PROJECT EXP LEDGER
HM
PRO FILE K-1
REG SUM
HH
HK
HP
PRO EXP
42 M
PRO EXP
HP
SH EXP
HR
SUMMARIZE TO SUBHEAD
SUMMARIZE TO APPROPRIATION
HR
SH EXP
HT
APP EXP
PRO EXP
HP
SH EXP
HR
APP EXP
HT
80M-84M
EDIT
HV
200
HX
201
HZ
202
EV
206
EY
220
BLK. 4 21 M
206 DATA K-1
E D
BLK. 4 63 M
220 DATA K-1
EX
44 M
PRO FILE K-1
HM
BLK. 4 25M
ADJ K-1
FD
UPDATE PROJECT FILE, NONEXPENDITURES
BF
PRO FILE K-1
45M
PRO FILE
BF
AE
CON TROL
ZZ
1. PICKUP TITLES
2. SELECT DATA SUMMING EXPEDITURES
3 COMPUTE DATA
JB
STATUS DATA
46M
STATUS DATA
JB
SORT
APP
2ND
3RD
4TH
PRO
ITEM
JD
STATUS DATA
47M
STATUS DATA
JD
1. SUM TO 4TH, 3RD, 2ND KEY AND APP.
2. PRODUCE DATA FOR STATUS RPT. AND SUMMARY SHEET
JF
300 DATA
JH
SUM DATA
48M
300 DATA
JF
SUM DATA
JH
EDIT PROJECT STATUS REPORT OR SUMMARY SHEET
JK
300
JM
SUM SHEET

Figure 24

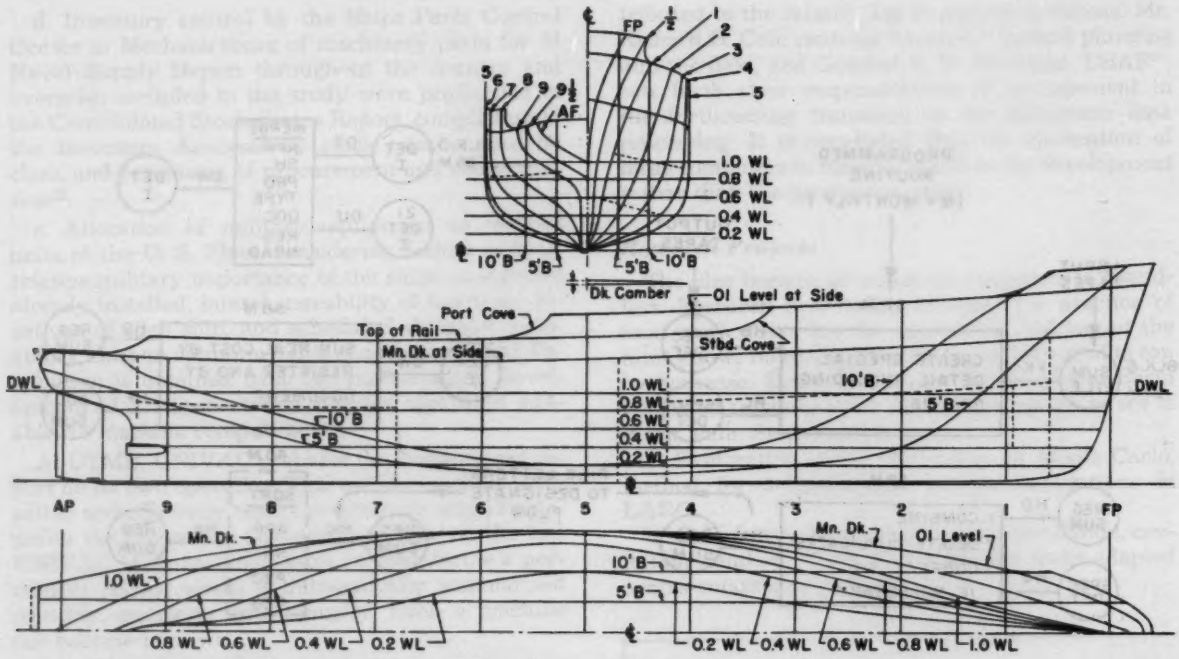


Figure 25. Preliminary lines for this oceanographic survey ship have been used to develop a means for fairing final hull lines by a general purpose computer.

c. Rigorous method for calculating moderately-loaded propellers using induction factors[26].

d. Increasing rate of convergence of the iterative procedure in computer codes to reduce machine time.

e. Development of automatic programming including selection routine, merge generator, sort generator and input-output routines.

f. Techniques in the fields of linear programming and operations research applicable to solution of an important class of logistics problems on high-speed computers.

g. Evaluation of the charactron tube for application to plotting, high-speed printing, and supervisory control monitoring.

h. Feasibility of using a digital computer in regions where an analogue computer is unstable.

i. Design and development of transistor sub-assemblies.

j. Engineering diagnostic routines which perform all normal computer operations but with reduced memory capacity.

k. Service routines for use by the programming and engineering personnel of the laboratory.

l. Numerical methods of solving the 2-dimensional multi-group diffusion equation.

m. Profiling of water tunnel and full scale propellers from the output of a computer program, thereby eliminating the present intermediate step of using a model as a master.

An intriguing prospect is the possibility of fairing ship lines mathematically on a computer rather than manually on a drawing board[27], Figure 25. In place of a single analytical function for a ship line as proposed by Rear Admiral David Taylor[28], Dr. Feodor Theilheimer utilizes a number of cubic curves that are connected continuously, and with continuous first and second derivatives, at juncture points. As the stiffness of splines and battens is used graphically so the computer program uses the beam theory numerically, as the restraining forces of ducks are readjusted manually so the computer equalizes the calculated reaction forces by least squares, as wiggles are avoided instinctively by the ship's draftsman so the computer program recognizes extraneous points of inflection, and as the draftsman arrives progressively at increasing fairness so the machine continues for a finite number of iterations until a surface satisfying the specified fairness criterion has been found. Once the shape of ship surfaces can be handled numerically, computer integration procedures lead readily to the calculation of the scalar measures and coefficients of form.

The Future

If ship lines can be faired and coefficients of form determined in a computer, can this novel approach be extended? Perhaps so. It is conceivable that a matrix of ship forms can be programmed, in which systematic series of the past and future will serve

Figure 26. The 1/10 scale model of the new DTMB Maneuvering Basin is generating a short-crested sea by pneumatic wavemakers along two adjacent sides. A sea surface of this complexity may soon be definable by computer programs.

as check points, and that even variables such as route stability, turning characteristics and seaworthiness can be explored much more rapidly than by present methods. It may yet be possible to obtain ship motions, accelerations and hull strains[29] from a numerically-expressed ship form moving through a mathematical short-crested sea, Figure 26. To be sure, it is inconceivable that ship model tests can be eliminated but the results of those undertaken can doubtless be made more generally useful.

Unquestionably, the swing to universal computers for scientific and engineering calculations will continue. Naval engineers need only experience what computers are like and what they can readily do to become enthusiastic users. As familiarity and appreciation grow, demand for computer time will increase. The savings in engineering manpower alone are sufficient to sustain the momentum, quite apart from the extended possibilities which are opened.

Cost is recognized quickly as a clear limitation to the growth in number of computers. LARC will cost

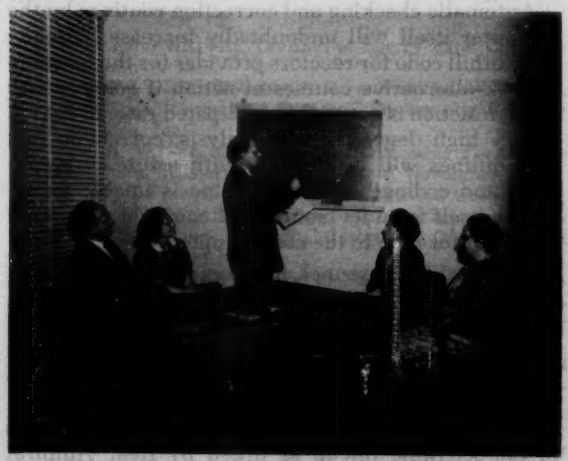


Figure 27. Women are Co-Leaders in Naval Mathematics in the Applied Mathematics Laboratory. Here Dr. Feodor Theilheimer, Dr. Jean Porter, Dr. J. W. Wrench, Jr., Dr. Ruth Davis, and Dr. Elizabeth Cuthill discuss new applications of computers in naval engineering.

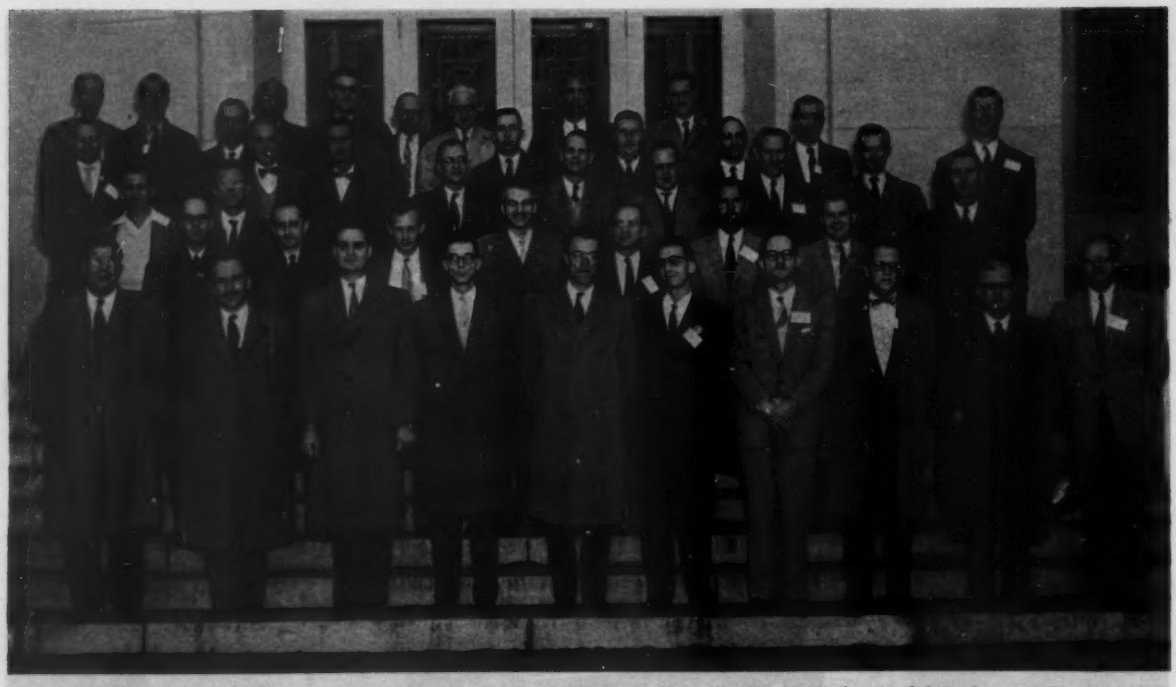


Figure 28. The first meeting of the Senior Navy Mathematicians, held at the David Taylor Model Basin on 9 January 1957, marked a milestone in Naval mathematics.

over 3 times as much as UNIVAC I but will have 100 times the capacity. This is a favorable growth ratio and economically in a sound direction. Moreover, the trend to solid state computers is increasing the reliability and decreasing the maintenance. The ratio of productive operating time to total time is expected to increase from about 85 to 95 per cent. The improved ruggedness will be particularly favorable to shipboard applications.

Automatic checking and correction routines by the computer itself will undoubtedly increase. Already the Cuthill code for reactors provides for the machine to seek alternative courses of action if convergence of the function is not at the anticipated rate. In LARC a very high degree of self-analysis, correction and sub-routines will be possible with astute programming and coding[12]. If the machine is unable to extricate itself from its troubles, of course it must type out a call for help to the console operator.

In regard to personnel, naval engineering definitely has a new look. Women of marked scientific and philosophical ability have moved into positions of management and technological leadership, and a large measure of present and future progress is in their capable hands, Figure 27. From Carderock way, it appears that women are both taking their places in the scientific lineup as urged by Rear Admiral H. E. Rickover[30], and sustaining the revolution described by Rear Admiral A. G. Mumma [31]. Another personnel facet is the formal recognition recently of common interests and opportunities among the senior naval mathematicians, Figure 28. Indications are that naval mathematicians are here to stay as long as marine engineers and naval architects.

In the field of business and logistic type problems, universal computers may some day relieve us of routine tasks to the same order of magnitude as the industrial revolution relieved us of physical tasks. Automatic programming techniques will go far to improve the flexibility of these type problems. Even the industrial complex of the Bureau of Ships, although relatively far advanced in electronic data processing, has hardly begun to feel the impact on management and industrial operations.

The real driving force to exploit the rich potentialities of universal computers in management is coming, it is believed, not from computer engineers, nor mathematicians, nor even intermediate supervisors, but from upper management levels. As these levels understand the principles and applications of computers to the same extent as they appreciate steam plants, diesel engines, nuclear reactors, radar, hull structures, and hydromechanics, naval management goes out in front inspiring and realizing broad attainable benefits. This is the case now and bids well for the future. The visionaries of our future Navy are ambassadors of computer philosophy.

As has been pointed out by H. Polachek, development of a mathematics for data processing offers a strong challenge for the future. Representative operations in this field are sort, collate, match and merge, just as we have add, subtract, multiply and divide

in scalar arithmetic. In this sense, the shoe fits the pure mathematician, for neither the logic nor the notation of information processing are yet available.

In the field of engineering, experience in the laboratories of the David Taylor Model Basin has shown that effective use of universal computers can be accelerated when the engineers themselves obtain a working knowledge of basic principals, many of which are outlined in this paper. Thereby, experimental data can be recorded initially in a form suitable for direct input into rerun of a programmed problem.

Even in the distant future, it seems unlikely that general purpose calculators, highly self-automated though they be, will ever be able to compete with the fantastic agility of the human brain to blend experience and judgment into a decision. For the Naval Engineers' Annual Banquet, the considerations in seating 1800 people at 10-man tables in 3 different rooms to suit 130 different companies are so complex that LARC, starting 69 years ago with the founding of the American Society of Naval Engineers, would still be calculating, whereas our Secretary and the Banquet Committee start at 0930 on a Saturday and finish before daybreak the next day. An effort was actually made to program the Banquet seating on computer with this finding.

Speed in digital computers shows no early signs of leveling off. The Harvard Mark I in 1944 performed operations at the creditable rate of 1 per second, yet the DTMB LARC will complete in 45 minutes as many operations as Mark I in over 12 years. Concurrently, research to improve mathematical techniques, sub-routines, and convergence rates is reducing the number of operations required for the same result.

I am reminded of two prophetic papers which made a vivid impression at the time, one by Dr. Theodor von Karman in 1940[32] and the other by Dr. Vannevar Bush in 1945[33]. "The time will soon come when mathematical analysis will be applied in almost all branches of engineering" and "there will come machines to handle advanced mathematics—sufficiently bizarre to suit the most fastidious connoisseur of the present artifacts of civilization." Both prophesies approach fulfillment in the Men, Mathematics and Machines at the David Taylor Model Basin.

ACKNOWLEDGMENTS

Throughout the short but pioneering and flourishing history of the Applied Mathematics Laboratory, its accomplishments have been due primarily to the pronounced mathematical and management abilities of the Chief Mathematician, Dr. Harry Polachek, and to the outstanding staff which he has assembled. Of paramount importance during the critical founding period of the Laboratory were the vision and leadership of Rear Admiral A. G. Mumma, USN, then Commanding Officer and Director of the David Taylor Model Basin; his vital guidance was carried on by his successor, Rear Admiral W. H. Leahy, USN. As head of the Computer Division of the Bureau of Ships and Chairman of the Computer Advisory Panel, Mr. A. E. Smith has supported and collaborated in progress at every step of the development of the DTMB Applied Mathematics Laboratory.

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The IBM 704, selected by the Navy Department as the heart of the computing facility for Project Vanguard, will operate continuously after the launching of the satellite to predict the orbit of the sphere. In these calculations the computer will rely principally on its high-speed magnetic memory storage. The storage can accommodate 65,356 "words," any one of which can be transferred from the memory to the arithmetical unit for processing in 12 millionths of a second. Seventy per cent of the arithmetic calculations which take place are executed at the rate of 41,700 per second. For example, in the time required for the sound from a radio loudspeaker to travel across a room, the 704 can multiply two ten-digit numerals fifty times, placing the decimal point correctly in each result.

INSTRUCTOR LIEUTENANT COMMANDER
JOHN D. HARBRON, R.C.N.R.

THE ROYAL NAVY AND THE NUCLEAR AGE

THE AUTHOR

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EVERY GREAT AGE of man has its great institutions of law and order. From the Pax Romana of ancient history came Roman law. From the Pax Britannica of the Victorian and Edwardian reigns came the rule of law of the Royal Navy.

Roman law is still with us, though the number of national legal structures where Roman law forms the basis has dwindled with the spread of non Anglo-Saxon concepts of government in our age. But the once all-powerful influence of the Royal Navy as an arbiter between peace and war in some far nook or cranny of the world where lived Kipling's "lesser breeds without the law," is irrevocably gone.

From 1805, the glorious year of Trafalgar, until 1914, Britain's Royal Navy fulfilled the old Tudor adage about British sea power, "keepe then the sea which is the walle of Englande." And a British warship, whether a small gunboat on a punitive mission against unruly natives, or a powerful battleship on an imperial state visit to an imperial neighbor such as Czarist Russia or the German Empire of the Hohenzollerns, proclaimed to illiterate savage and sophisticated European emperor alike that one of Her Majesty's ships, whether large or small, represented British world sea supremacy, no matter what the mission.

Toynbee, writing about the smug sense of solidity and permanence which were the marks of Victorian England, was once reminded of the Biblical quotation, "the lines have fallen unto me in pleasant places; yea, I have a goodly heritage." Part and parcel of this seemingly endless national self-satisfaction and political and imperial repose of 60 years ago was the policeman and protector role of the Royal Navy.

No British government pursued a line of foreign policy, whether of a serious or routine nature, without knowing where British sea power stood in the matter. During the relative quiet of Victorian and Edwardian England, the Royal Navy saw service mainly in the building of empire; though wars like the Crimean venture of the 1850s, and Mediterranean "war" scares such as the one that ended in the occupation of Egypt in 1882, meant more solid naval action.

Today, however, the role as well as the place of the Royal Navy in British sea power is as far removed from what it was in the 1890s as are all other British naval and military requirements in the nuclear age.

None of the yardsticks of determining naval superiority in Victorian England and none of the concepts of strategy or of the ancillary purposes of naval power as understood then apply today. All is changed.

This is the nuclear age. As one of the world's old-

est institutions, the Royal Navy which has passed through so many technical stages must now face the most complex one of all, preparation for sea warfare in the nuclear age. More serious than this, the Royal Navy may have to answer a question, unheard of 60 years ago, "are navies outdated?"

One can scarcely imagine the captain of any one of the 60 proud battleships Britain possessed in 1911, the year of the last, great pre-1914 Coronation naval review, ever being asked such an impertinent question. And yet, the same navy, which today has not a single battleship in commission, prepares to face an era whose demands are so very overwhelming, not only in their scientific applications, but also in their political and economic ones.

MEETING THE NEW ERA

British naval leaders have already begun a program of fleet conversion to meet the offensive and defensive needs of nuclear warfare at sea. Britain has been the pioneer in some of the most radical as well as some of the most important changes in aircraft carriers in meeting the challenges of naval aviation in the age of ever-faster and more versatile jet aircraft. Examples are the angled deck and the steam catapult.

In those fields of British naval endeavor where operational methods have continued basically unchanged since the days of steam, new concepts of control, administration and function are slowly coming about. For example, the whole prospect of naval coaling stations, conveniently located around the world, is no longer so important now that modern naval vessels have bigger oil bunkers and oil-fired propulsion and fleet tankers of increasing speed available to them. Other Royal Navy fleet responsibilities, such as the maintenance of traditional colonial stations, like the China Station, have been swept away by the violent political changes brought about during World War II. The China Station has been a thing of the past since 1941. It has been suggested that the West Indies Station, which will become an anachronism when the British West Indian islands gain independent status, become the preserve of the Royal Canadian Navy which has been training in the area since the 1920s.

And the nuclear age will come with some difficulty and much heart-rending to the Royal Navy, because long-nurtured supports of pre-nuclear British naval strategy are now out-of-date. The chief of these was the once invulnerable "lifeline to India." India ceased to be a jewel in the British diadem 9 years ago. The vital naval stations along the "lifeline" are either gone or jeopardized. Gibraltar is still the physically impregnable rock, but is it strategically what it was in 1900? Suez, currently in the headlines, has been handed over to Egypt, a very recent Moslem power. Malta seeks organic union with the United Kingdom, and air power eliminates the distance factor in the Mediterranean when we realize that a modern British Fleet Air Arm carrier jet aircraft can fly from "Gib" to the gates of Suez in a few hours.

However the nuclear age actually offers new strengths to the Royal Navy. Two immediately come to mind. The first is that the new Royal Navy will be a small, compact nuclear unit; a tight fleet, possibly serving more in coastal and home waters than it has done since the Middle Ages, but well-equipped with aircraft carriers, the capital ships of the future, fast cruisers and ultra-modern anti-sub destroyers to fight in an atomic war. The First Lord of the Admiralty, J. P. L. Thomas recently described the Royal Navy of the future in this way:

> [It will be] . . . an elusive and hard-hitting fighting force . . . a mobile offensive force which can be quickly deployed wherever required.

In the last two months, this activity has become the top priority one for the civilian and service planners of the Royal Navy. The new guided missile strategy for the three British armed forces, the main development of the Eisenhower-Macmillan talks at Bermuda in April and the publication of Britain's latest defense White Paper on the future guided missile era for British arms, have laid down the Royal Navy's role in the nuclear era.

The remaining few battleships of Britain, once supreme symbols of undisputed British sea power, will go to the scrappers immediately, all except one. HMS Vanguard, the only battleship Britain has commissioned since World War Two, will remain as flagship of the reserve fleet.

The confirmed "battlewagons" of the future R.N. will be her 12 new and modernized carriers, to which one more, now completing, will be added by 1958. The main offensive aircraft of the new Royal Navy will be the long-range missile supplied by the USA and a new supersonic bomber, the NA-39 to carry them, but also one of the last naval aircraft according to the Bermuda agreement, Britain will build. The new nuclear age tactics at sea will be built around the small task force, made up of aircraft carriers, plus very fast anti-submarine destroyer escorts, all equipped with defenses against atom bomb attacks at sea. The escorts will have submarine detection equipment sensitive to a submarine's activities miles away under the sea, compared to the several thousand feet limited range of World War Two's sonar equipment.

The second is the emergence of small, uni-functional, well-trained commonwealth navies. These already have assumed many of the Royal Navy's pre-1939 jobs abroad. Canada and Australia have the largest. The former Indian Empire now has two navies, one for India and one for Pakistan. New Zealand and the Union of South Africa also possess modest naval strength. To all of these Britain has contributed generously of ships, from aircraft carriers to landing craft, and of men from senior administrators to junior technical experts on loan.

THE DECADE SINCE 1945

In the 50 years from the death of Victoria to the outbreak of the Korean War, the Royal Navy has undergone tremendous and unexpected changes. When Edward VII became king in 1901, the generally

accepted "Two Power Naval Standard" of his mother's reign, (that is, if the Royal Navy had as many battleships built or building as did the next two most powerful navies in the world combined, all would be well for England), was already being challenged. Imperial Germany, catching up virtually from scratch in battleship construction, shattered the "Two Power Naval Standard" by the war summer of 1914.

And a Britain which could afford 52 battleships in commission in 1914, came out of the 1914-1918 holocaust exhausted and impoverished as she was to be again in 1945. The second big change was the naval disarmament of the 1920s and 1930s. What Winston Churchill called the "naval holiday" reduced R.N. battleship strength to less than 15 when Britain went to war against Germany again in September, 1939.

Greater than these was the rise of airpower as a factor in war at sea and the emergence of the aircraft carrier. As everyone knows, the aircraft carrier was firmly entrenched as "the new capital ship" before the fleets went home to peace in 1945 after many wartime years of combined and amphibious operations all over the globe.

But the changes offered by the post-1945 world are greater than any the Royal Navy knew before. After the second global conflict, the Royal Navy faced not only the atomic age but the world of blatant and unbending nationalism which pressed heavily on colonial areas where naval bases still remained. Singapore, the proud, unbeatable Far Eastern naval bastion of the 1920s and 1930s, whose guns were to face the wrong way when the moment of trial came in 1941, was never to be the same again. Within her waters, carrier aircraft of the Imperial Japanese Navy destroyed two of Britain's newest battlewagons in less than a day's work.

Today, Singapore demands independence as an island republic in the British Commonwealth. What the enraged Victorians would have called "peoples of the white man's burden" such as Egypt, Ceylon and even Chile make unheard of demands on Britain's imperial territories, in the face of a weakened naval power, to get out of Cyprus, Trincomalee, abandon Antarctic claims. Was not Captain Robert Scott, R.N., who gallantly died in Antarctica in 1912, the symbol of adventure to every English school boy in the pre-1914 era? And Spain has started to nag Britain for the return of Gibraltar.

While nationalism whittles at the empire and what remains of the structure of British naval bases which once ringed the globe, another fact presses harder yet on the Royal Navy. This was and is Britain's difficult financial position in the postwar era.

Immediately after the war the R.N. was in desperate straits in this regard. Not only was the expensive prospect of complete fleet re-design obvious, even in 1946, but the money and the trained personnel to do it were not there. After the war, the trained officers and men either wanted to go back to civilian life or younger men did not want to join the naval service at a lower pay than civilian life offered them. And in the late 1940s, Britain lost, not only to the Navy but to the nation as a whole, thousands of trained technical men and women who immigrated to the Commonwealth nations and to the U.S.A.

Linked with this was the uncertain postwar family life overseas for naval officers, men and their families. Life abroad was no longer what it had been in the halcyon days of the 1920s. A postwar posting in Hong Kong, for example, has been described by one wartime R.N. naval hero as, "an adventure in getting into debt." The high cost of living, the low naval pay, the loss of respect for the white man's institutions by native peoples in the area, a result of Japan's wartime military successes against Western colonial powers, are all hard to take. Bonus pay for service in foreign stations surrounded by unfriendly nations which were once friendly, or at least acquiescent, was not worth the effort.

As expected, the further restrictions on Britain's armed forces, imposed by the Suez adventure last November, have had some repercussions on the Royal Navy. But these have not been as serious as foreign experts anticipated. Two events, the post-Suez oil shortage and the new scheme for a reduced guided missile-equipped British defense system which Mr. Duncan Sandys, Britain's new Defense Minister, discussed in Washington with Secretary of Defense Charles Wilson, affect the Royal Navy. The oil shortage, accentuated by the payment in dollars for local fuel oil supplies for R.N. ships at certain foreign stations, has resulted in still further reduced cruising and training schedules abroad.

The changes in the future pattern of British sea power are primarily those announced by Mr. Duncan Sandys following the Washington talks last January and those published in the most recent British White Paper, on defense a result of the talks between Prime Minister Macmillan and President Eisenhower at Bermuda in April.

The eleven reserve naval air squadrons of the R.N. have been disbanded and with them has ended the trained civilian reserve of trained naval air pilots. In addition to the elimination of remaining capital ships still in commission and to the priority now to be given to nuclear weapons at sea, as mentioned earlier, a new company to be known as Vickers Nuclear Engineers, a subsidiary of the world-famous Vickers-Armstrong shipbuilding empire, will build Britain's first atomic submarine. Propulsion will be based on a pressurized water reactor.

While these changes and new activities are revolutionary for Britain's Navy, they are not nearly as sweeping in their appearance as the changes to be brought about in the British Army and the Royal Air Force. Work on further super-sonic bombers and fighters for the R.A.F. will stop. Contraction of the British Army regular units will mean the disappearance of proud regiments with battle honours covering three centuries of land warfare for British arms. But the end of conscription, which has continued in

Britain since 1939 and the overall reduction of all the armed forces from 690,000 to 375,000 by December 1962 will affect the navy. It's already having problems finding enough highly trained technicians and officers to man and control the new gear in the new atomic-age ships already in commission.

Even if the Suez debacle had never happened, the Royal Navy was already faced with the problem of continuing to "show the flag" in such traditional areas of British sea authority as the West Indies Station, for which major warships could no longer be supplied. The use of destroyers and even frigates as flagships on remaining foreign stations is now commonplace. Even the future of many of these smaller vessels is in jeopardy following a statement by the Admiralty last year that a number of frigates and minesweepers would be sold to the navies of Britain's smaller N.A.T.O. allies.

THE "NEW NAVY"

With this gloomy background facing the oldest institution of arms which Britain possesses, it is short of astounding the way in which the Royal Navy of 1956 is as prepared as she is for nuclear warfare. In spite of such heavy odds against her and in spite of the vast wartime sacrifices in ships, men, financial outlay and national talent, the Royal Navy today is an efficient inheritor of both the great battle honors and peacetime achievements of its 1,000 year heritage.

In meeting the challenges of the jet air and nuclear ages, the Royal Navy can point to the following great accomplishments:

(1) Ship design for the Nuclear Age:

The Royal Navy, which revolutionized naval warfare in 1906 with the first all-steel, all "big-gun warship, H.M.S. *Dreadnought*, has converted H.M.S. *Hermes*, a new 36,800 ton carrier, into a vessel capable of resisting radio-active contamination from atomic explosions. H.M.S. *Ark Royal*, second carrier to bear the name, can, as one British journalist puts it: "close herself up like an oyster and keep out contaminated air." Her engines can be operated by remote control by men in a special decontamination compartment. Like most vessels, she would probably be doomed in an area of complete H-bomb destruction, but could survive on the fringe of such a blast. Two light fleet carriers are also undergoing changes to meet the nuclear age. These are H.M.S. *Albion* and H.M.S. *Centaur*.

Light fleet carriers for both the R.N. and British Commonwealth navies, on which construction stopped after the war, are being finished as up-to-date carriers bearing the latest landing and flying devices as well as atomic decontamination techniques. One of these, H.M.C.S. *Bonaventure*, was turned over to the Royal Canadian Navy in Londonderry in January.

Today, Britain has about 250 ships in commission. Cruisers, on which new construction ceased completely in 1946 for lack of funds, and destroyers, on which much money has been spent and into which the latest electronic anti-submarine gear has been built, will be the new punching arms of the Royal Navy. After almost a solid decade of steady, unremittent day-by-day submarine warfare in two world wars, the British have always given priority to the development of anti-submarine vessels, techniques and equipment. Even on the heels of wartime demobilization in 1945, the big wartime anti-submarine school at Londonderry in Northern Ireland immediately got under way with new research. Few Englishmen will ever forget that submarine action sent over 21 million tons of British shipping to the bottom in two major sea conflicts. As the Korean emergency advanced, Britain prepared to meet the threat of the Soviet Navy which already had an estimated 300 undersea boats.

British naval leaders needed no reminder of the nasty work Nazi Germany did with less than 60 submarines in the first six months of the 1939-1945 war. Inevitably, therefore, anti-sub attack methods have become part of the untried but ever-present theories of how nuclear war under the sea would be waged. What could happen to big, vulnerable British ports, dockyards and coastal towns into which all of the food and fuel of the nation pours daily, if they were destroyed by a sneak Soviet submarine firing an atomic-headed missile from its deck gun?

British experience in firing atomic-headed missiles from subs is one of that country's best kept secrets, as well as methods of combatting an atomic attack on port installations. But lack of funds keeps wide-scale research down. However, the Royal Navy is aware, as is the U.S. Navy with the seaward defenses of the United States coastal cities in mind, of the danger of sneak harbor attacks as they could be made during an atomic war.

On July 24th last, H.M.S. *Girdle Ness*, the first British guided weapons vessel, was commissioned at the R.N. Dockyard at Devonport. Though she will be a trial ship and not intended for the active fleet, her guided missile armament is undergoing full sea trials. Missiles are loaded into her untouched by human hands, traveling up rails from the dockside to the mounts situated in racks forward of the bridge. Called "Sea Slugs," the ship's guided weapons are anti-aircraft in nature and can be loaded, trained, elevated and fired mechanically.

In May, the first of Britain's six big, new 2,000 ton anti-submarine frigates completed trials and was accepted into service. She is H.M.S. *Torquay* and carries the latest types of "Limbo" ahead-thrown-weapons, situated near the stern and fired over the ship from the asdic control center below decks. Her sister ship, H.M.S. *Whitby*, was provisionally accepted for service in the Royal Navy in August.

Britain also leads the world in operational use of subs with the hydrogen peroxide motor, an invention of Dr. Walther, the German naval scientist. The H.M.S. *Explorer* submarine class embodies most of the revolutionary speed requirements of the Walther

motor as tried out very briefly but very successfully by the dying Reich in the last months of World War II. With small, fast M.T.B.'s, the Admiralty is experimenting with gas turbine propulsion motors and trials are now under way in the English Channel.

(2) Naval air power:

Britain has developed and modernized aircraft carrier operations to a point unexcelled in any other navy except that of the United States. Today, even the U.S. Navy makes wide use of most of Britain's postwar carrier research. British inventions such as the angled flight deck, the steam catapult, the deck mirror are all found aboard the U.S.S. *Forrestal*, the world's largest aircraft carrier. Hangar damage control differs in the Royal Navy from the U.S. Navy because British carriers have always had steel decks; whereas many United States carriers have wooden ones.

In the field of jet naval aircraft, Britain announced in January of this year the arrival of the NA-39 proto-type supersonic naval strike aircraft. The NA-39 built by the Blackburn organization, will have wings machined from a solid block of light metal, further lightened by hollowing. This is contrary to the conventional metal skin over internal framework of most aircraft. The NA-39 also incorporates speeds well in excess of 500 m.p.h. and yet, at the same time, will have slow flight requirements for carrier deck landings. This will be accomplished by including a device using jet power to control air flow over the wings at low speeds by blowing air down over the landing flaps. The Douglas Skywarrior, built for the U.S. Navy, approximates the performance and expectations of this new British fighter.

(3) Research:

The Royal Navy, quietly, but persuasively, has been combining research in related fields where a union of weapons might make for better defense in the case of nuclear conflict. The chief example of this is its confidence in using helicopter sweeps to track and sink submarines from carriers. The helicopters carry an airborne asdic set called "dunking sonar" which is lowered into the water. Organized sweeps of helicopters, operating in teams from a carrier or from more than one carrier, are presenting one of the most effective anti-submarine "hunter-killer" techniques yet devised. The sub cannot attack an asdic set which appears and disappears from nowhere; nor can the slow, hovering helicopter be shot down if it has a covering umbrella of the carrier's fast jet naval air fighters to protect it.

One of the few positive results of the British-French landings at the Suez ports was the capture by the Royal Navy of Soviet ship-borne computer gear waiting to be installed in the Russian *Skoryi* class destroyers given to Egypt by the USSR last August. Not only did possession of this equipment give a new perspective to the future of British naval research planning; but it offered the West an unexpected insight into Soviet advance in this field. The Soviet Navy, unlike the Royal Navy, combines gunnery and torpedo computer activities in one mechanism. Torpedo speeds up to 60 knots could be computed on the Russian equipment taken at Port Said. "It's most unlikely the Russians are computing torpedo speeds in excess of conventional requirements," said one R.N. ordnance expert at Portsmouth's ordnance naval depot.

ROYAL NAVY AND U.S. NAVY

Though compact and hard-hitting as her leaders promise, the future Royal Navy, like previous smaller navies in her days of supremacy, must rely on the soundest of relations with the dominant free naval power in the world. Today, the United States Navy, the largest and technically the most complex naval force in history, must bear much of what the Victorian Englishman called, "the weight of empire." In the Mediterranean, for example, the U.S. Sixth Fleet rides where as recently as 1935, during the Italo-Ethiopian crisis, the Royal Navy held the naval balance of power of the inland sea and prevented Mussolini, the Italian dictator, from starting a major war to gain his colonial ambitions.

Elsewhere in the world, where only yesterday the arrival of an R.N. gunboat or the landing of British marines quelled pirates or a locally obstreperous warlord, today the presence of a U.S. fleet is needed to contain as well as protect ideologies, to say nothing of convincing the armed might of a nation like Communist China that though the largest Western navy has changed its nationality, it has not changed its basic role, to keep the seas free.

Military pacts to maintain freedom, of the N.A.T.O. type, were nonexistent in pre-1939 days. Today, they mean stronger joint endeavor between the two big English-speaking navies of the world. But their concepts of naval power can conflict as well. It is inevitable that some Royal Navy personnel, even some at the highest level, view the dominance of American sea power today with mixed feelings of jealousy and pride in their very old naval service. To the British naval officer who feels this way probably comes the memory that the American Navy is a mere child of warfare in the face of ten centuries of British naval experience. He will remind himself that the Royal Navy was not exactly an agent in the creation of American sea forces in 1776, but rather a main deterrent to such an eventuality. The appointment of Admiral Fechteler to command all N.A.T.O. North Atlantic naval units a few years ago brought the biggest howl from the British press that United States-British naval relations in the postwar era have produced. In the North Atlantic area where so many of the battle honors of Britain at sea had been gained, the appointment of a foreign admiral to be in overall command of British naval units was openly called "insulting."

American reaction, where it has existed, has taken the form of intimating that Britain should be grate-

ful that such a compatible as well as such a powerful navy as the U.S. Navy is in existence to assume the reigns of leadership and to carry on the world role which shrunken British naval strength no longer can carry on alone. But most thinking British and American naval officers and men are fully aware, that while the United States has assumed many of the 19th Century naval commitments of Britain in the world, she has done it in many places with the partnership of the Royal Navy.

Where these opinions may still hold in the two fleets today, they are held as minority opinions indeed. It's the cooperation of American and British naval power which is essential to the working out of all vital matters. Take the utilization of naval bases in the nuclear age. While Britain still clings to her "colonial" bases such as those at Singapore, Malta and Aden, the U.S. Navy relies on N.A.T.O. and leased bases. *The Economist*, the highly rated British magazine of business and politics, explained the position of Britain and America in regard to naval bases in this way:

> In the first place, British bases are part of the Anglo-American web of sea-power; the Americans take them for granted. They assume that Singapore will be denied to the Communist powers; and they assume that at Aden and Cyprus, Mombasa or elsewhere, naval power will be exerted to preserve Middle East oil. Because Britain has the existing colonial bases, the British navy's share of the western naval task is that which can be contributed by ships operating from these bases. N.A.T.O. bases are poorly located to influence either the Middle East or South East Asia.

There has also been a reconciliation between British and U.S. sea power in the theories about "long-legged" and "short-legged" navies. That is, the U.S. Navy, taking as an example the U.S. Sixth Fleet in the Mediterranean, rotates its home base every six months and follows the "long-legged" navy tradition of American sea power. The so-called "long-legged" navy operates with perhaps double the ships and double the men. It is far from dockyards and from naval bases with which it keeps in touch by means of an extensive fleet train of oilers, fleet tenders, ammunition ships and so forth.

The big, powerful "cities" class cruisers of the U.S. Navy of the 1920s and 1930s, which kept the sea lanes open between San Diego, Pearl Harbor and Cavite in the Philippines, were built to serve a "long-legged" navy. Though they did not enjoy the comforting presence of the vast array of supply ships which U.S. fighting vessels of the 1950's can use, they were large enough to be self-sufficient over the thousands of miles of Pacific waters which separated America's Far Eastern naval bases.

The Royal Navy tradition is toward the "short-legged" navy relying on a well-laced string of bases and smaller, faster cruisers making for more mobility at sea. Bases, the British contend, allow for on-the-spot storage of fuel, ammunition and provisions 'round the world. They also offer facilities for resting and training crews between cruises. They possess to a lesser or greater degree docking and maintenance facilities and they can be used as command centers in wartime.

This difference of opinion about cruisers and bases in the "long-legged" and "short-legged" navies existed in 1927 when the Geneva Conference on cruiser strengths was unable to break the deadlock of opinion between the American big cruiser theorists and the British theorists, who saw only small cruisers relying on a global string of land bases. Today, the increased complexities of a nuclear age, when an atomic war could be launched near or on any one of the Royal Navy's or U.S. Navy's bases, has long since reduced a lot of the bases controversy to the harmless realm of the naval arm-chair strategist.

Undoubtedly, the permanent threat of a nuclear war has done more to firmly unite Anglo-Saxon naval might than any other single event, with the possible exception of the comrades-in-arms relationships of the two World Wars.

This has expressed itself in both two-way and three-way relationships. The two-way relationship is a result of the growth of national organisms of naval defense within the developing British Commonwealth. Since 1945, as more nations emerged from the colonial status within the British Commonwealth, so did their navies. Since 1945, Britain has given, sold or loaned at least 80 warships to British Commonwealth navies all over the world. The Royal Australian Navy and the Royal Canadian Navy have received between them 4 light fleet carriers. Eight cruisers have gone to the Royal Australian Navy, Royal Canadian Navy, Royal New Zealand Navy and the Navy of the Indian Republic. A further 26 destroyers, 19 frigates, 8 minesweepers, 4 LST's and 11 harbor defense vessels have gone to Pakistan, Australia, India, Ceylon, Burma, the Union of South Africa and Nigeria.

A part of this two-way relationship between Britain and new British Commonwealth nations, some of them like India, Pakistan, Burma and Ceylon not of Anglo-Saxon stock, has been the feeling that these Commonwealth beneficiaries should assume some of the burden of naval commitments in their area, a burden now relinquished by the Royal Navy. Mounting nationalism, affecting some remaining Royal Navy bases abroad such as in Ceylon, where the nationalist premier, S. W. R. D. Bandaranaike, is asking the British to leave Trincomalee naval base, is being soothed by assisting the naval force of Ceylon to take over the present Royal Navy duties there. And there are, of course, the ever-present budgetary restrictions on the Royal Navy today, cutting down many of the pre-war demands on the Royal Navy in the Far East, in African waters and in the West Indies.

When we look at substantial Commonwealth naval entities such as those of Canada and Australia, we realize that mutual Commonwealth naval defense in conjunction with American naval power can be an active and real factor in knitting together nuclear age defense at sea.

This is the three-way relationship. It means co-operation on all levels, strategy, training, technical "know-how", fleet exercises between the U.S.A., Britain and the British Commonwealth. This relationship is already in existence and working very well. Looking at it from the viewpoint of the Royal Canadian Navy, which has not only carried out exercises with joint units of the U.S.N., R.N., R.A.N. and R.N.Z.N., but constantly trains officers and men in both British and American fleet training establishments, the three-way naval relationship of the nuclear age of naval power may be the greatest potential which Anglo-American navies can offer a would-be aggressor in any future nuclear warfare at sea.

Steam catapults are now being built into the Netherlands' aircraft carrier Karel Doorman (ex.-H.M.S. Venerable), being modernized at Rotterdam, and the French aircraft carrier Clemenceau, under construction.

The British Admiralty has created a new senior position in the engineering branch of the Royal Navy with responsibility for the operational and material aspects of nuclear propulsion. The first officer to be appointed to the position is Rear Admiral G. A. M. Wilson, who will hold the title of Deputy Engineer-in-Chief (Nuclear Propulsion).

"ENGINEERING"

ADVANCED POWER REACTORS

ACKNOWLEDGEMENT

This reprint consists of three articles which were published in the November 30, 1956, and December 7, 1956, issues of "Engineering." The first part, which is of an introductory nature, is concerned generally with the scope of the United Kingdom program and with the possible course of future development. It is a staff article based upon talks given by Sir Edwin Plowden and Sir John Cockcroft at a meeting of the International Bank for Reconstruction and Development, and on papers presented by Sir Christopher Hinton and Mr. R. V. Moore at the "Symposium on Calder Works Nuclear Power Plant" held in late November 1956, by the British Nuclear Energy Conference.

Part II contains a discussion on a very-high-temperature (VHT) gas-cooled reactor. It is a staff article extracted from Mr. R. V. Moore's paper mentioned above and from papers presented at a "Symposium on Nuclear Gas-Turbine Power Plants," held by The Washington Section of The American Society of Mechanical Engineers.

Part III, which compares two distinct types of reactors, was written by Mr. G. W. K. Ford, research manager in charge of experimental criticality at the Dounreay Establishment of The United Kingdom Atomic Energy Authority.

I—TOWARDS HIGHER OUTPUT AND EFFICIENCY

IN DESIGN as in exposition, it is always necessary to go from the known to the unknown. Thus, Calder Works, a novelty of technical achievement, is based on engineering principles which have been long familiar. The reactor pressure vessels, for example, owe something to wind-tunnel construction, and the heat exchangers to conventional boiler practice. But eventually, techniques, methods and materials must be adapted to the special requirements of the new process. Reactor technology is in an early stage of technical development and as such is of broad interest, since it embraces all the main engineering disciplines, civil, mechanical, electrical and chemical, and since, in addition, many problems remain to be solved. Moreover, given a basic knowledge of reactor principles (the chain reaction, the use of moderators and the action of coolants), the virtues and disadvantages of any reactor system are easily appreciated, though the task of comparing several systems technically or economically is necessarily complex. Thus there is much in favor of developing a tried system, which is known to be practicable. Chosen originally in this country because vast quantities of pure cooling water were not available and because of its inherent stability, the gas-cooled reactor offers the best immediate prospect in Britain, and it is thought that, even at a later date, it may in modified form prove competitive with such advanced designs as the sodium-cooled graphite-moderated system. But in any case a properly balanced nuclear economy requires a number of different systems to be operated concurrently.

Considerable technical advances have already been made since the Calder Hall plutonium plant and power station was designed, and it seems likely that the gross power output of the initial stations will exceed that of Calder Hall "A" by a factor of three with little increase in cost. Thus, instead of 92 MW the electrical rating of the first Central Electricity Authority stations may be as high as 300 MW, and the capital cost per kW less than £120, though the initial investment of fuel may be about £30 per kW. Coal stations cost some £55 per installed kW. In addition, operating temperatures of early stations are likely to be low (in the region of 400 deg. C) and the thermal efficiency only a little more than 25 per cent. Burn-up of uranium fuel in these reactors is likely to be about 3,000 megawatt-days (MWD) per tonne, (coal equivalent: 10,000 tons per ton of uranium). Plutonium will be produced, which may serve as enrichment for the fuel of future power reactors, and it is thought that a reasonable credit

to allow for it is about 0.1*d.* per unit of electricity sent out. Its value, however, will depend to a great extent on the development of convenient means of extracting it from irradiated fuel elements and reprocessing it. Owing to its toxicity, handling too presents a major problem. (Plutonium, incidentally, if burnt completely would yield the same energy as 3 million times its weight of coal.) From these figures and the fact that coal costs about £4 a ton and uranium ore about £10,000 a ton, it has been estimated that power from the projected stations will cost about 0.6 *d.* a unit or 7 mills (one mill = 0.001 dols.); they will thus be roughly competitive with coal-fired stations.

ECONOMIES OF SCALE

It is important to point out that with nuclear power stations there are great economies of scale, and though with later reactors using enriched fuels this may not be so true, they are likely to be economic first in the larger sizes. Thus, in the early stations the advance beyond Calder Works is due not only to the changed emphasis from plutonium to power production, but also to an increase in reactor size. This has been made possible by increased thickness or strength of reactor pressure vessel. Increase in reactor size gives higher heat output since the neutron flux can be flattened, and since the maximum rate of heat removal can be associated with a larger volume of core. Increased vessel thickness also makes possible a rise in coolant-gas pressure (perhaps 150 lb. per sq. in. as against 100 lb. per sq. in. for Calder Hall) and hence increased efficiency of heat removal, or reduced circulating costs, though with diminishing returns as pressure increases. In addition, capital costs increase but to a smaller extent as the core size is increased. Other improvements may result from the use of slightly higher gas outlet temperatures made possible by improved canning material (a zirconium alloy instead of Magnox, for example) and consequently enhanced thermal efficiency. Subsequently, by use of a beryllium-alloy can, it may be possible to raise fuel-element temperatures by about 100 deg. C. Thus, by 1965 heat ratings may have increased by a further factor of two and the capital costs of nuclear stations (neglecting their advantage in fuel costs) be little more than those of coal-fired stations.

IMPROVING BURN-UP

Though canning costs are likely to be higher, this may be offset by a fall in the primary cost of uranium. However, the main prospect of reducing fuel costs is by increasing burn-up. One method is by re-cycling the plutonium produced, thereby supplementing the depleted uranium 235. Another is to burn the plutonium where it is formed within the element; this seems likely to require the use of ceramic fuel elements but a burn-up of 10,000 MWD per tonne or 30,000 tons of coal equivalent per ton of uranium may be achieved.

It is apparent that by 1963-64 by-product plutonium will be produced in substantial quantities and, depending on the cost of separation processes, will probably be cheaper than uranium 235 produced in diffusion plants. Moreover, use of plutonium means conservation of nuclear fuels since the bulk of the natural uranium then becomes usable. It appears that plutonium may be profitably used in at least four ways. These are:

(1) It could be used in new thermal reactors requiring initial enrichment by re-cycling, for example, high-temperature gas-cooled reactors. These will be considered in a later part of the article.

(2) It could be used in fast-neutron, breeder reactors operating on a plutonium-uranium 238 cycle and producing power. This leads to balanced fast and thermal reactor schemes in which a comparatively large fraction of the uranium 238 is used, arising from the fact that fast reactors breed more fissile material than they consume. An experimental fast reactor is currently under construction at Dounreay, in the north of Scotland.

(3) It could be used in fast or thermal reactors as the fissile material for a plutonium-thorium "transition cycle" producing power and uranium 233 as a by-product. The uranium 233 might subsequently be used in a self-sustaining uranium 233-thorium cycle in thermal reactors, if these prove practicable, or might be used as the fissile material in fast reactors, breeding from uranium 238 or thorium.

(4) It might be used in power plants requiring highly enriched fuel, for example, plants designed with a large power-to-weight ratio.

Studies of other systems are in progress. For example, loops are to be inserted in DIDO concerned with the following reactor types: water-moderated reactors, high-temperature gas-cooled reactors, aqueous homogeneous reactors, reactors using uranium-bismuth slurry as fuel and organic-moderated reactors. Organic-moderated reactors are likely to use a liquid, diphenyl, as moderator and are thought to offer considerable advantages in view of the low system pressure at which they can operate. Work is also being carried out on the sodium-graphite system, though its economic advantage over advanced gas-cooled reactors may not prove substantial. The boiling-water reactor in various forms is also believed by some to offer the prospect of high efficiencies. Many of these require enriched fuels and may be competitive with conventional power plants in quite small sizes. The homogeneous system may achieve very high heat ratings and improved heat transfer, since fuel and moderator are intimately mixed, thereby effecting better contact between fuel and cooling medium. In addition, improved burn-up may be obtained since there will be regeneration of fuel within the reactor. It is therefore an important long-range prospect and the means whereby power at 0.4*d.* or 0.5*d.* per unit (competitive with hydro-electric power) may eventually be achieved. This, however, is still at least 10 or 15 years away.

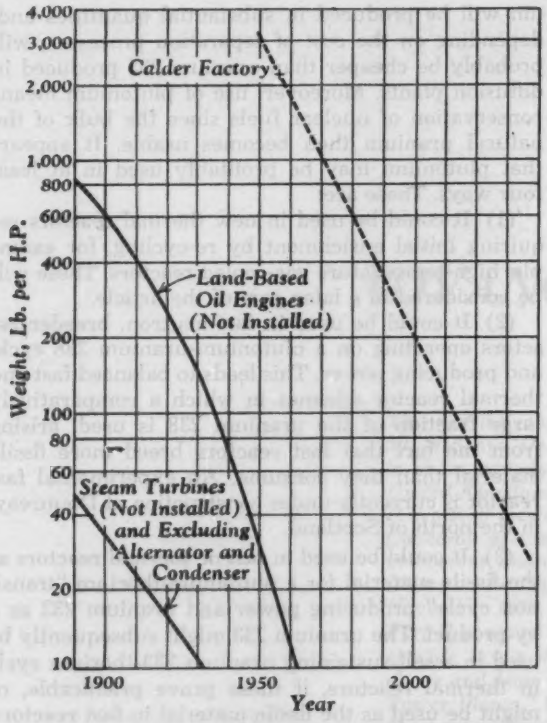

Figure 1. Comparison of steam turbines, land-based oil engines and Calder Works in terms of weight per unit output. By analogy the power-weight ratings of future nuclear stations may be obtained.

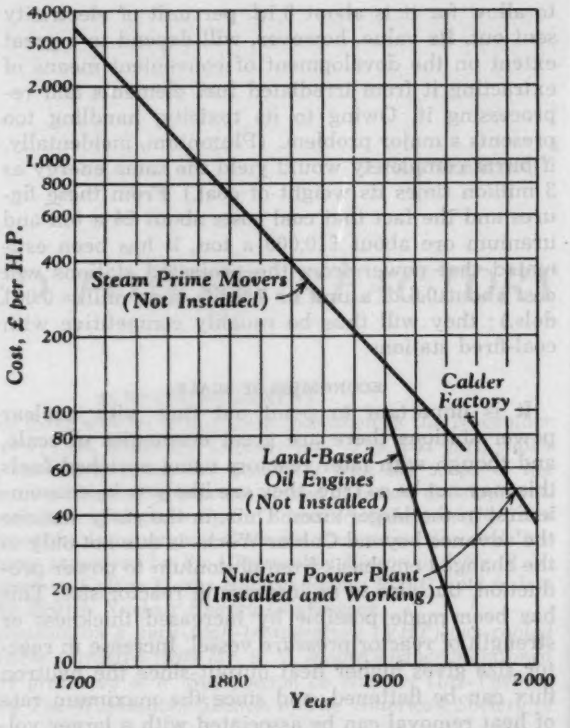

Figure 2. Comparison of 1954 equivalent cost of steam prime movers, land-based oil engines and Calder Works, showing possible future trends in the capital cost of nuclear power plant.

FALLING CAPITAL COSTS

Another method of computing the future cost of power from nuclear reactors is by historical analogy. Past experience tells us that the weight per horsepower and capital cost (in terms of real money per h.p.) fall with the passage of time for all types of prime mover. This is indicated in the graphs shown in Figs. 1 and 2. Fig. 1 plots against time the weight per h.p. of land-based oil engines and of steam turbines and shows the progressive decrease in weight per h.p. which accompanies the development of better materials of construction and better techniques of design. On this graph appears a curve which assumes the same general characteristic for the weight per h.p. of land-based nuclear power plants, and a study of this curve is interesting because it gives some indication of the date at which the weight per h.p. of economical nuclear plants can be expected to fall to levels at which such plants may be installed economically on moving platforms. The second chart gives the cost per h.p. of steam prime movers and of land-based oil engines and again gives an imputed curve for the capital cost of nuclear power plants. From the White Paper it is possible to deduce a capital cost per kW of £125 for the earlier power stations of the Calder Hall type and this is used as the starting point for the curve in Fig. 2. It must, of course, be recognized that the curves in Fig. 2 are not strictly comparable, because the cost for the nuclear power plant includes the civil engineering work; this has been done because much of the civil work (such as the biological shield) is an integral part of the installation and cannot be separated from other civil engineering work on the station. In addition, it might be noted that the higher the stage of technical development, the more technical knowledge there is for a new technology to adopt. High-temperature materials, for example, have been developed for gas-turbines and may also have given a lead in reactor metallurgy. Nevertheless, the historical comparison is a fair one, and although the curves are not strictly comparable, Fig. 2 is useful in showing trends.

Reduction in capital cost in accordance with the hypothetical curve shown in Fig. 2 would give in 1975 a cost per unit of 0.5d. and this takes no account of reduction in cost of the ancillary processes (such as chemical extraction) which might also be expected. This tallies with the estimate mentioned earlier, based on the homogeneous reactor. These improvements in capital cost should be seen in the light of the fact that, whereas in a conventional power plant roughly three-quarters of the cost per unit sent out represents fuel and operating costs and only one-quarter capital charges; in a nuclear station capital charges account for nearly two-thirds of the costs. The effect of reduced capital charges per unit is thus

very important. Some indication of the part played by capital charges in the total cost per unit sent out at Calder Hall is given by Table I.

TABLE I. *Cost per Unit of Power Sent Out from Calder Works*

Cost component	Cost	
	d.	Per cent
Capital charge	0.56	53
Fuel inventory charge	0.10	9
Fuel consumption charge	0.35	33
Operation and maintenance	0.05	5
Total	1.06	100

It is of interest that at present the cost of electricity sent out by conventional stations per unit is about 0.6*d*. whereas the cost to the consumer is roughly 1.4*d*. per unit. Thus 0.8*d*. of the total, which corresponds to distribution and other charges is outside the scope of the nuclear engineer.

LONGEVITY

In the opinion of Sir Christopher Hinton, the merits of the Calder Hall type of reactor and the partial improvements that can be made in its design are such that plants of its kind will still be built 25 years from now, and will alone enable us to retain our present lead for at least a decade. In the second half of that 25 year period, however, it will be replaced in certain land-based applications by reactors of higher rating and in the very long term it will, for most purposes, be superseded by such reactors. Reduction in weight per h.p. beyond a certain point will not be possible with the use of gaseous coolants; to get further we must achieve the higher ratings which can only be achieved by employing liquid coolants. The use of these coolants at present is not industrially practicable because they involve technological problems which have not been solved; they demand materials which are not in commercial supply; or they call for the use of enriched fuel. In time these problems will be overcome, and highly rated reactors using liquid cooling will be employed; first, in those special applications where the user can afford to pay inflated prices for reduced weight per h.p. and then, as the cost of the special materials demanded falls with increasing experience of their production, for normal industrial applications.

GAS-COOLED REACTORS

The remainder of the article will be largely concerned with one class of reactor, that based on the gas-cooled graphite-moderated system. In considering the developments which this system may undergo, it will be seen, for example, that a new range of gas-cooled reactors becomes possible with the introduction of fuel elements having increased surface-to-mass ratios and clad with an alloy of high melting point. Such reactors will probably need initial enrichment, although their design may enable them to operate on re-cycled fuel with a natural-uranium feed. The higher heat ratings which may thus be obtained should extend their application beyond base-load power stations to plants producing small quantities of power at a worthwhile cost. In addition, still higher temperature systems may be developed in which metals would be excluded from the core and use be made of ceramic fuels dispersed in the graphite moderator. Reactors of this kind may lead to the economic use of gas-turbine cycles and the elimination of intermediate heat exchangers. These and other possibilities are discussed in greater detail below.

As a starting point we may consider a nuclear power station costing £125 per installed kW, operating at 80 per cent load factor and 25 per cent efficiency. It should be observed that the plant availability necessary to achieve a high load factor demands means of fuel-element charging and discharging superior to those at Calder Hall. Fig. 3 shows the cost per unit sent out as a function of fuel burn-up in mega-watt-days (MWD) per tonne of uranium, priced at £20,000 per tonne. The fuel elements are assumed to have no residual value. It is clearly important that the fuel should be capable of as long a

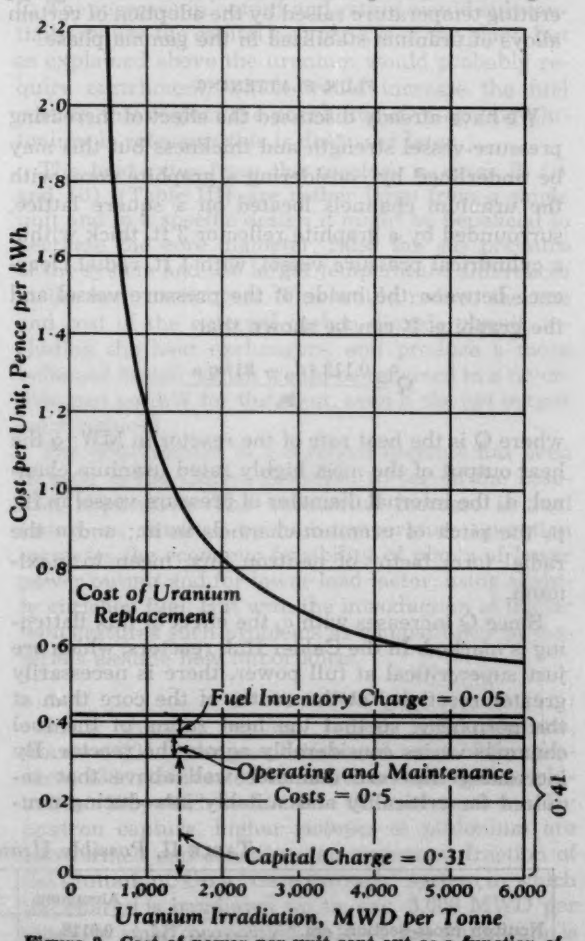

Figure 3. Cost of power per unit sent out as a function of fuel burn-up in megawatt-days per tonne. Results are for a reactor with a capital cost of £125 per installed kW, operating at 80 per cent load factor and an efficiency of 25 per cent.

period of irradiation as possible before the accumulation of fission products inhibits the chain reaction, particularly up to about 2,000 or 3,000 MWD per tonne. The ability of a natural-uranium charge to achieve a long irradiation depends mainly on two factors; first, the neutron balance, necessary for the chain reaction, must be maintained, and secondly, the fuel elements must withstand the effects of irradiation damage under the operating conditions, without an excessive number of failures. As the uranium 235 content of the charge is consumed, it is replaced to some extent by plutonium formed from uranium 238 by neutron capture, and a small fraction of the plutonium so formed is itself fissioned. Recent experimental results from the Calder plant tend to confirm that 3,000 MWD per tonne is obtainable before the chain reaction ceases. The metallurgical limits on the life of the fuel elements arise from the tendency of uranium to increase in volume when irradiated at temperatures approaching the alpha-beta change point of 600 deg. C. Indeed, it is likely that 3,000 MWD per tonne may be exceeded and the operating temperature raised by the adoption of certain alloys of uranium stabilized in the gamma phase.

FLUX FLATTENING

We have already discussed the effect of increasing pressure-vessel strength and thickness but this may be underlined by considering a graphite core, with the uranium channels located on a square lattice, surrounded by a graphite reflector 3 ft. thick within a cylindrical pressure vessel, with 1 ft. radial clearance between the inside of the pressure vessel and the graphite. It can be shown that

$$Q = \frac{0.113\,(d_p - 8)^2\, q\, \alpha}{p_s^2}$$

where Q is the heat rate of the reactor in MW; q the heat output of the most highly rated uranium channel; d_p the internal diameter of pressure vessel in ft.; p_s the pitch of uranium channels in in.; and α the radial form factor of neutron flux, mean to maximum.

Since Q increases with α, the effect of flux flattening is marked. In the Calder Hall reactors, which are just supercritical at full power, there is necessarily greater reactivity at the center of the core than at the periphery, so that the heat rating of the fuel channels varies considerably across the reactor. By increasing the core diameter well above that required for criticality and suitably introducing neutron-absorbing material, or rearranging the fuel-channel spacing, or using enriched fuel in certain channels, a comparatively uniform flux distribution may be obtained (flattening). Thus a greater number of fuel channels may be operated at heat ratings approaching the maximum permitted by considerations of temperature and rate of heat removal. Heat removed can itself be increased by raising the system pressure, but to a diminishing extent as pressure increases. Coolant pressure necessarily depends on pressure-vessel thickness, which also, of course, governs reactor size and hence the degree of flux flattening and the total volume of core associated with heat production. These quantities are related in the graph shown in Fig. 4. Increases in coolant pressure should, of course, be considered in connection with the pumping power required as a percentage of reactor heat output. Reduction in lattice pitch, p_s, also clearly brings an advantage but squeezing beyond a certain limit introduces mechanical and nuclear problems.

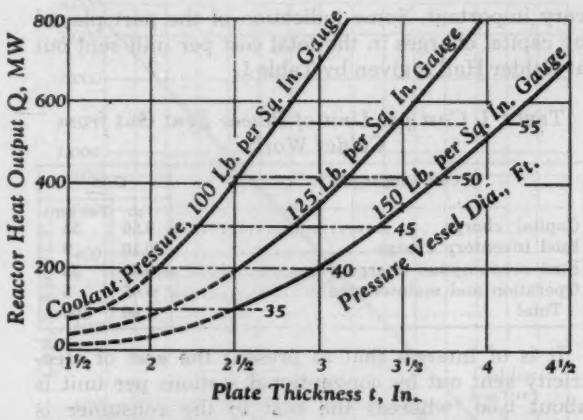

Figure 4. Graph showing variation of reactor heat output with coolant pressure, pressure-vessel diameter and vessel plate thickness.

TEMPERATURE AND CLADDING

Raising operating temperatures is also a source of improvement, since both heat output and thermal efficiency will be increased, though the cost of fabricated fuel elements may offset this to some extent. Fuel-element cladding material should be of low neutron cross-section and is used to prevent escape of fission products and chemical reactions between

TABLE II. *Possible Uranium Cladding Materials*

	Aluminum	Magnesium	Beryllium	Niobium	Zirconium	Stainless steel (18/18/1)
Neutron cross-section, $cm.^{-1}$	0.0118	0.0023	0.00011	0.061	0.0076	0.227
Melting point, deg. C.	660	650	1,284	2,415	1,850	1,500
Thermal conductivity, CHU./h. ft. deg. C.	130	90	70	36.4	14.4	9.2
Density at 20 deg. C.	2.7	1.74	1.85	8.57	6.5	7.9

uranium and coolant. Some possible materials are listed in Table II; stainless steel is included though its poor neutron efficiency makes it unsuitable. In addition, it can be seen that beryllium, niobium and zirconium, though withstanding higher temperatures, have poorer thermal conductivity. This coupled with increased heat flux means that fin efficiency might be so low as to make extended surface ineffective so that it would be necessary to spread the primary surface. But it should be noted that a rod has a low surface to mass ratio and therefore gives high reactivity; thus to change to some other design may call for the use of enriched fuel.

TABLE III. *Comparison of Extrapolated Calder Design (case A) and Plant with Maximum Fuel-Element surface temperature of 600 deg. C. (case B)*

	Heat output (MW)	Efficiency (per cent)	Average uranium fuel rating (MW per tonne)	Electrical output (MW)
Case A: Larger Calder design	400	25	2	100
Case B: High-temp. reactor				
(i) Flattened	1,400	31	5.8	433
(ii) Unflattened	1,100	31	4.5	340

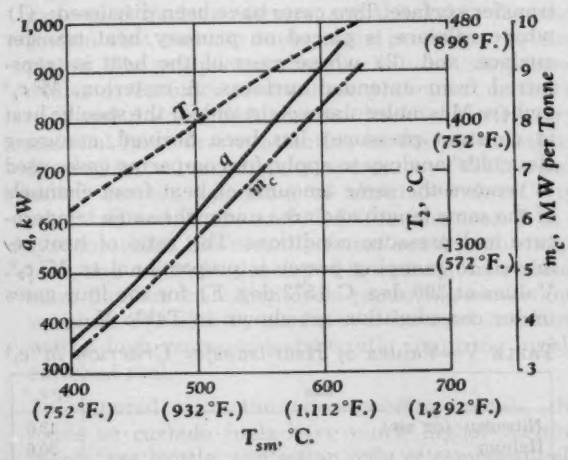

Figure 5. Variations of channel heat rate q, channel gas outlet temperature T_2 with maximum fuel surface temperature. Figure 6 shows effect on efficiency.

The effect of raising fuel surface temperature can be gathered from Fig. 5, which plots channel heat rate, q; the average rating of the uranium, m_c, in the most highly rated channel; and channel gas outlet temperature, T_2, against maximum surface temperature of the fuel. Fig. 6 shows the variation of overall efficiency with bulk gas outlet temperature T.

Data from Figs. 5 and 6 have been used to compile Table III, which compares an extrapolated Calder design, having a reacting core 40 ft. in diameter with a plant of the same size core but having a maximum fuel-element surface temperature of 600 deg.

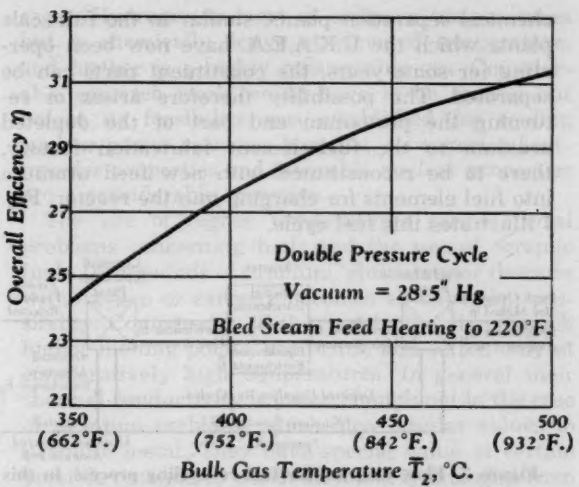

Figure 6. Effect of bulk gas outlet temperature (from reactor core) on overall thermal efficiency.

C. The increase in output and rating would substantially reduce the capital cost per kW of the plant, but as explained above the uranium would probably require enrichment, which would increase the fuel cost. In this respect the possibility of re-cycling plutonium is relevant; this is discussed later.

The heat rates from the reactors in cases B (i) and (ii) (Table III) are rather large from a single unit and in a specific design it might be beneficial to decrease the core diameter, raise the gas pressure of the system and use larger temperature differences in the heat exchangers. This would reduce the size and cost of the external carbon dioxide circuit, including the heat exchangers, and produce a more balanced design, which would be reflected in a favorable cost per kW for the plant, even if the net output were reduced.

The development of gas-cooled reactors has been focused in the United Kingdom so far on the base-load application. The substantial increase in fuel rating, m, obtained by high-temperature operation increases the economic feasibility of plants of lower power output and for lower load factor, using slightly enriched fuel. But with the introduction of higher temperatures such problems as compatibility of materials assume new importance.

FUEL RE-CYCLING

In a thermal reactor fueled with uranium, uranium 235 undergoes fission and some of the uranium 238 is converted by neutron capture into plutonium 239 which is fissile to thermal neutrons. By neutron capture, higher isotopes of plutonium are also formed and constitute an important fraction of the plutonium. On a "once through" system in which the charge is irradiated up to, say, 3,000 MWD per tonne, a small proportion only of the plutonium is burnt and the discharged fuel elements contain plutonium, depleted uranium and fission products. In

chemical separation plants, similar to the full-scale plants which the U.K.A.E.A. have now been operating for some years, the constituent parts can be separated. The possibility therefore arises of returning the plutonium and part of the depleted uranium to the fuel-element fabrication factory, there to be reconstituted with new feed uranium into fuel elements for charging into the reactor. Fig. 7 illustrates this fuel cycle.

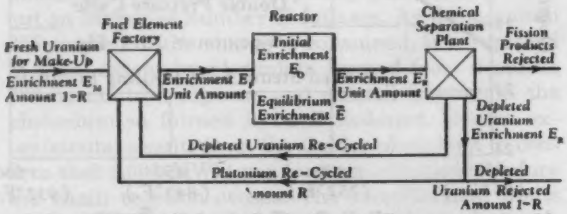

Figure 7. Flow diagram for fuel re-cycling process. In this way it is possible to reduce demand for natural uranium and to provide a source of enrichment other than uranium 235.

If the plutonium is re-cycled, eventually an equilibrium condition is reached in which the rate of burning plutonium is balanced by the rate of production of fresh plutonium. This is possible in a reactor with a conversion factor of less than unity, if the fissile material, short of the amount required for the reactor to operate, is made up from uranium 235 in new uranium fed into the system. The analysis of such a system is complicated by the fact that as the plutonium is taken to longer irradiations the higher isotopes influence to an increasing degree the performance of the reactor. By successive neutron capture plutonium 239 can become plutonium 241, plutonium 242 and plutonium 243. Plutonium 243 is radioactive with a short half-life (5 hours) and effectively decays almost immediately on formation to americium 243, which would be removed in chemical processing after irradiation. Plutonium 240, 241 and 242 build-up during the approach to the equilibrium system, when the rate of their formation is equal to their rate of destruction by natural decay or neutron capture. Plutonium 240 and 242 are not fissile isotopes, but plutonium 241 is fissile and produces neutrons during fission. The effect of the higher isotopes of plutonium can be seen from Table IV; the values are typical of a reactor of the type shown in Case B of Table III. The mean moderator is assumed to be 700 deg. K. The table shows the number of plutonium atoms required to replace one uranium 235 atom without altering the reactivity. The adverse effect of plutonium 242 in the system is clearly demonstrated by these figures.

TABLE IV—*Number of Plutonium Atoms Required to Replace One Uranium 235 Atom Without Altering the Reactivity*

	Number of plutonium atoms
For pure plutonium 239 fuel	0.44
For 3,000 MWD per tonne plutonium from a natural uranium reactor	0.75
For equilibrium plutonium	2.38
For equilibrium plutonium without plutonium 242	0.99

It may be shown that potentially the important advantages of fuel re-cycling are (1) it could reduce the natural uranium requirement to meet a given power demand by a significant factor; and (2) under certain conditions, applicable to gas-cooled graphite-moderated reactors, designs requiring initially a charge of slightly enriched uranium, can be subsequently fed with natural uranium once equilibrium conditions are reached. It should also be noted that an alternative procedure, as previously stated, would be to achieve higher values of plutonium burn-up where it is formed within the fuel element

COOLANTS AND CERAMIC FUELS

For reactors so far discussed it has been assumed that the coolant gas is carbon dioxide. Investigations carried out have shown that, in addition, the following gases might be considered for cooling power reactors: hydrogen, helium and nitrogen. Coolants must be compared on a number of criteria—safety, cost, availability, purity, thermal and irradiation stability, chemical compatibility, neutron absorbing properties, the degree to which they become radioactive—all in addition to their heat-transfer properties. In comparing the heat-transfer properties of gases, reference must be made to the type of heat-transfer surface. Two cases have been discussed: (1) where reliance is placed on primary heat transfer surface, and (2) where most of the heat is transferred from extended surfaces. A criterion, $M^2 c_p^3$ (where M is molecular weight and c_p the specific heat at constant pressure) has been derived, assuming Reynolds' analogy to apply, for comparing gases used to remove the same amounts of heat from channels of the same length and area under the same temperature and pressure conditions. The ratio of heat removed to pumping power is proportional to $M^2 c_p^3$. Values at 300 deg. C (572 deg. F) for the four gases under consideration are shown in Table V.

TABLE V—*Values of Heat-transfer Criterion* $M^2 c_p^3$

Gas	$M^2 c_p^3$
Nitrogen (or air)	13.0
Helium	30.6
Carbon dioxide	31.4
Hydrogen	167.0

M = molecular weight, c_p = specific heat.

The ratio of pumping power to heat output for a given gas is proportional to the square of the heat output, so that by substituting, for example, hydrogen for carbon dioxide, an increase in heat output by a factor of 2.33 could apparently be obtained. However, with unchanged inlet and maximum fuel-element temperatures a drop in gas outlet temperature would occur. It has also been pointed out that the criterion is not completely satisfactory, because the heat-transfer area is a variable dependent on the gas properties, and unacceptable area might be needed to obtain a given performance. The same criterion applies also to transverse fins of the type used

in Calder Works, for which Reynolds' analogy does not apply, but for which a fin-efficiency correlation can be made. Similar criteria could no doubt be developed for other types of extended surface. If a more suitable gas is substituted for the original one, and an attempt made to restore the ratio of pumping power to heat output, the outlet temperature from the reactor can be expected to fall seriously in all cases of extended surface, owing to the reduced efficiency of the extended surface.

The only satisfactory way of comparing the performance of different gases is to evaluate for a specific design. In general, when this is done the differences are not so marked as expressions like ($M^2 c_p^3$) suggest. Carbon dioxide was the gas chosen for the Calder Hall reactors because it was the best compromise between all the requirements. As the temperature of reactor systems is raised, new conditions will be created and helium or nitrogen may supplant carbon dioxide as, comparatively, they are inert gases. Hydrogen is inert at ordinary temperatures but is chemically active at elevated temperature, and further is a highly inflammable gas. Considerable research work would have to be carried out before its feasibility was established for cooling nuclear power reactors; however, its superior heat-transfer properties and favorable nuclear properties are a considerable incentive.

The use of higher temperatures raises special problems concerning fuels and the use of ceramic fuels (compounds of uranium, plutonium or thorium with oxygen or carbon) becomes an important possibility. Compared with the metals, they have much higher melting points, are brittle and soften only at comparatively high temperatures. In general their thermal conductivity is lower, though not in the case of uranium carbides, which have similar values to uranium metal. They have special value in certain possible reactors in which all metal is excluded from the core and the fuel dispersed in the graphite moderator.

II—VERY HIGH TEMPERATURE REACTOR

In Part I we considered the advantages that higher temperatures would bring in the operation of gas-cooled nuclear reactors, and this led to the suggestion that ceramic fuels might profitably be employed. The prospect of using such fuels (comprising oxides or carbides of uranium, plutonium or thorium) and the fact that graphite itself is a refractory material have drawn attention to the possibility of developing a very-high-temperature (VHT) gas-cooled reactor, operating at about 800 deg. C, in which all metals are excluded from the core. It is a system, which has recently found considerable support, and might be developed to operate on a plutonium-thorium transition cycle producing power and uranium 233 as a by-product, or be used in plants with a high power-to-weight ratio requiring highly enriched fuel.

Compared with the corresponding metals, the oxide or carbide fuels have much higher melting points, are brittle, and soften only at comparatively high temperatures. Most ceramics have a thermal conductivity much lower than metals, but this is not the case with uranium carbides, which have similar values to metallic uranium. Some properties of the oxides and carbides of uranium are given in Table VI below.

TABLE VI—*Properties of Uranium and its Oxide and Carbides*

	U	UC	UC_2	UO_2
Melting point, deg. C.	1,133	2,250	2,260	2,500
Density	19	13.5	11.28	11
Thermal conductivity at 50 deg. C, C.H.U./ h. ft. deg. C.	3.75	4.6	0.47	0.29

Uranium oxide was used in the first reactor built in the United Kingdom (GLEEP) but uranium metal was later preferred as its density is higher, a favorable property from the nuclear point of view, particularly important when natural uranium is used. But as concentrated fissile materials become available, interest in the ceramic forms of uranium will probably return, so making possible the VHT reactor. Generally speaking, ceramics are more resistant to coolant attack than metals; uranium oxide (UO_2) is inert both to carbon dioxide and hydrogen. The oxide and the monocarbide (UC) are reasonably stable in air, although the higher carbides of uranium and thorium (UC_2 and ThC_2) are very reactive. In addition to their favorable high-temperature properties, there is some experimental evidence to indicate that their irradiation resistance is much better than that of the metals.

Naturally one of the most important considerations in designing a reactor is to achieve the highest possible heat output from a given quantity of fuel. Fuel rating is generally discussed in terms of heat removed from a given mass of uranium (MW per tonne), only a small proportion of which, in natural or slightly enriched uranium, is fissile material. This definition of rating carries with it a concept of the size of the plant; possibly some 20 per cent of the capital cost of a plant is inversely proportional to this figure. The fuel inventory charge is also reduced as the rating is increased. Another way of expressing fuel rating is in terms of fissile material, a concept more important in relation to fuel cycles. With natural uranium the fissile material rating is 140 times the uranium rating. Table VII shows the uranium and fissile-material ratings for the reactors discussed in Part I, and for a possible VHT reactor. With the

VHT reactor the possibility exists of virtually "diluting" the fissile material with the moderator, in this case high fissile-material ratings are possible, as is apparent from Table VII, and at the same time good neutron economy is preserved.

TABLE VII—*Uranium and Fissile-Material Ratings*

	Uranium rating, MW per tonne	Fissile material rating, MW per kg.
Calder Works	1.4	0.2
Case A: Larger Calder design	2.0	0.3
Case B: High temp. reactor (flattened)	5.8	0.8
Possible VHT reactor	—	1-2

At the high temperatures associated with this type of reactor—typically, a gas outlet temperature of 800 deg. C (1,472 deg. F)—the problems associated with materials are acute. Attaining a high degree of thermal and irradiation stability of the graphite and the ceramic fuel at high temperature and high neutron flux presents a formidable research problem. So does preventing the spread of fission products into the primary cooling circuit. These ideally should be confined to the fuel, as with conventional fuel elements clad in metal. The incentive for development, however, is high. It is calculated that the overall efficiency of such plants could exceed 40 per cent, while the high fuel rating would lead to a further reduction in the capital cost per kW, when compared with high temperature reactors with metallic cladding of the fuel elements (Case B of Table VII).

GAS TURBINES

Once the VHT system with its high gas temperatures has been developed, the use of gas turbines in reactor plants becomes worth while, and it is likely that a gas-turbine cycle will in fact be adopted for this type of reactor. For plants of large power output, a cycle generally similar to that developed by Escher-Wyss, of Zürich is applicable. Preliminary calculations for such a plant have been carried out at Chalk River, Canada. The general layout of the system is shown in Figure 8. The hot gas from the reactor feeds high and low pressure turbines, the latter driving the alternator. Two-stage compression with inter-cooling is used, and the high and low pressure compressors are driven by the high and low pressure turbines respectively.

In comparing the merits of carbon dioxide and helium, it has been shown that the rotating machinery for the carbon dioxide cycle has approximately half the volume of that required for the helium plant, but the heat exchangers have nearly doubled the volume, which suggests that marginally the carbon dioxide plant might be cheaper to build. In carrying out preliminary design calculations for a 60 MW (electrical) plant a gas pressure of 300 lb. per sq. in. abs. and a top gas temperature of 538 deg. C (1,000 deg. F) have been assumed. These conditions are particularly interesting as they probably represent something near the minimum conditions for such a

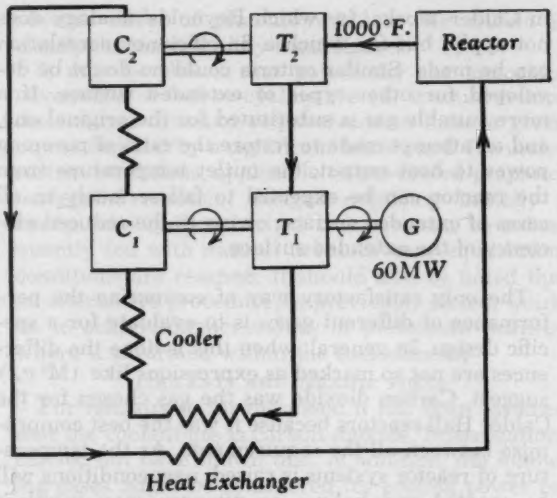

Figure 8. Gas-turbine cycle for reactor installation. The satisfactory use of the gas-turbine for nuclear power generation is likely to depend on the development of the very-high-temperature reactor.

cycle, requiring machinery that is large and costly yet possible to design and construct. Even at 538 deg. C the calculated efficiency is 29 per cent and if this temperature were raised to 677 deg. C (1,250 deg. F), this would increase to 38 per cent. For the capital cost of the plant to be competitive with steam plants it would appear, however, that the system pressure would have to be considerably higher than 300 lb. per sq. in. gauge.

It can be seen that to achieve reasonably economic operation, considerably higher gas temperatures are desirable, and it is here that the VHT system, operating at 800 deg. C, proves its value. But for the gas-turbine cycle shown in Figure 8 to be feasible, fission products would have to be contained within the reactor.

OPEN AND CLOSED CYCLES

As a basis for determining the most suitable gas-turbine plant for operation with a VHT reactor, it may be useful to consider some of the gas-turbine-reactor combinations already planned. It is also necessary to determine which of the available reactor coolant gases should be chosen as working fluid. These were compared in Part I and certain of them are employed in the gas-turbine-reactor systems discussed below.

Given that the reactor can deliver its thermal energy at a reasonably high temperature, say 650 deg. C (1,200 deg. F) to 800 deg. C (1,500 deg. F), both closed and open cycle systems may be used. With these conditions, the closed-cycle plant is said to offer flexibility of design, economy in space and weight, and good efficiency. The main advantage of the open-cycle gas turbine is its relative simplicity,

which is most effectively realized in the single-loop air-cooled system. Its natural field of application is thus in conditions where simplicity and reliability are preferred to highest possible thermal efficiency; these are most likely to occur in the case of small plants of the order of 1 MW or less, in which capital costs considerably outweigh fuel costs. As air is used as reactor coolant, working fluid, and auxiliary cooling medium, the plant is independent of both special gas and cooling-water supplies.

Design studies have been carried out for small gas-turbine reactor plants of 200 kW and 2,000 kW electrical capacity. For the former, an open-cycle plant has been chosen having an air-cooled reactor with a thermal output of 1,970 kW. The air heated in the reactor flows directly into the turbine. Beryllium oxide blocks are used as moderator, and the initial fuel charge is about 25 kg. of uranium 235. The turbine itself weighs only 854 lb. and tests have shown that with a turbine-inlet temperature of 720 deg. C (1,325 deg. F) it should provide the power required for a 250 kW generator. It should be possible to achieve this without raising the fuel-element temperature above 800 deg. C (1,500 deg F), The cycle efficiency is said to be 12.7 per cent and the terminal efficiency 10.2 per cent.

The 2,000 kW plant employs the Escher-Wyss Tuco 52 closed-cycle turbine and a nitrogen-cooled graphite-moderated reactor of 7 MW thermal output. Uranium oxide is used as fuel, and the initial charge is less than 25 kg. The nitrogen temperature at the turbine inlet is 660 deg. C (1,220 deg. F); the cycle efficiency is 34.5 per cent and the terminal efficiency 31 per cent.

A preliminary design study has also been made for a 15 MW closed-cycle gas-turbine nuclear power plant which may prove suitable for application to ship propulsion. The fuel-element material is metallic or cermet-metallic and the overall size of the reactor vessel is about 9 ft. in diameter and about 13 ft. in height, including the control-rod mechanisms. Nitrogen has been chosen as the working fluid, and for the moderator material both beryllium oxide and graphite have been considered. The turbine inlet temperature is 700 deg. C (1,292 deg. F) and the terminal efficiency is about 34 per cent. Initial calculations have also been made for a 240 MW plant using helium as the working fluid; these indicate that if the smaller system is feasible so is the larger. One of the outstanding problems to be solved is the construction of fuel elements that can withstand the high operating temperatures, mechanical and thermal stresses, and radiation damage. It is thus clear that the development of the VHT reactor, with its ceramic fuel dispersed in graphite moderator is likely to precede the satisfactory use of the gas turbine in reactor engineering.

SOME ADVANCED REACTORS

Six advanced reactors with associated plants are shown in Figures 9 to 14, inclusive. These have been reproduced from Atomic Energy Research Establishment photographs.

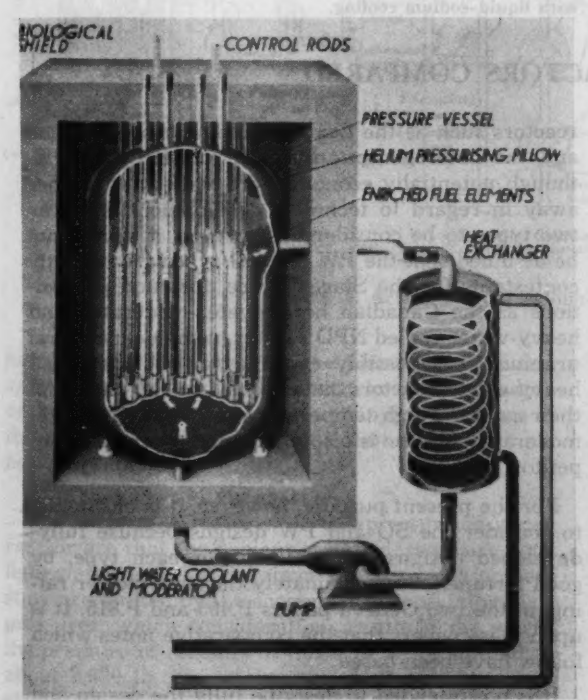

Figure 9. Pressurized-water moderated and cooled reactor.

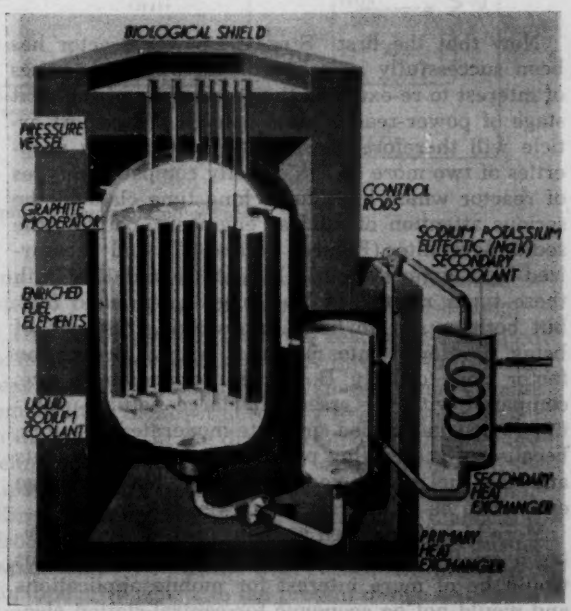

Figure 10. Sodium-cooled graphite-moderated reactor.

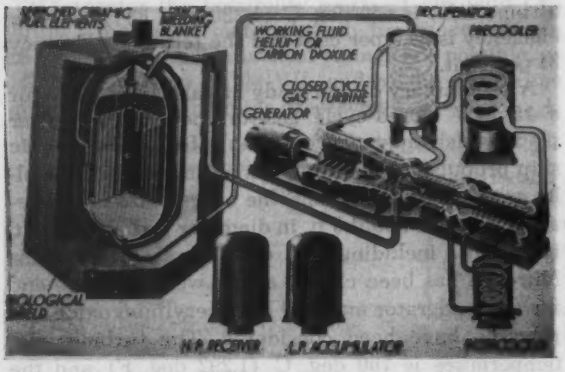

Figure 11. High-temperature gas-cooled reactor arranged to supply a gas turbine.

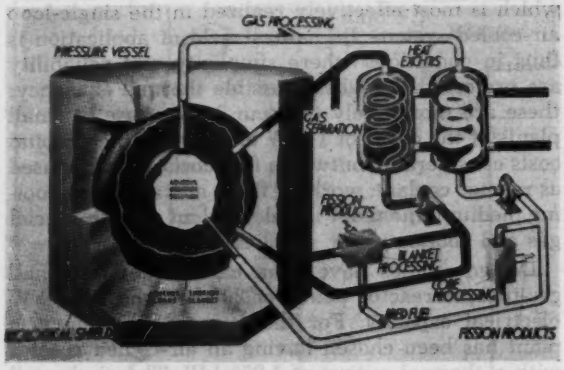

Figure 13. Aqueous homogeneous reactor with continuous fuel processing.

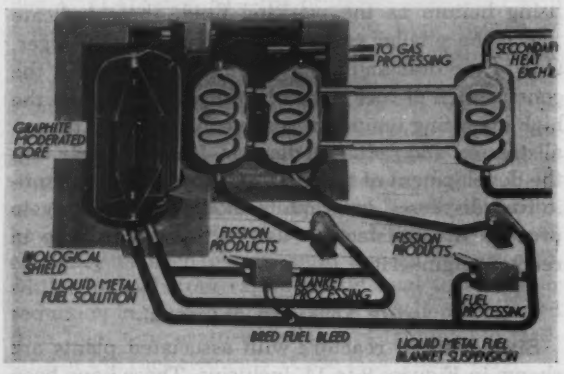

Figure 12. Liquid-metal (uranium-bismuth) fueled reactor with circulating system.

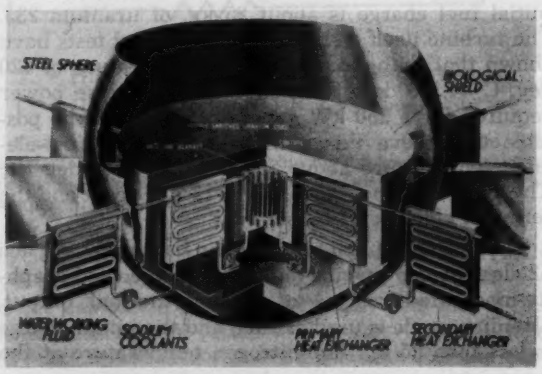

Figure 14. Fast breeder reactor (as building at Dounreay) with liquid-sodium cooling.

III—TWO POWER REACTORS COMPARED

Now that the first "Stage I" power reactor has been successfully launched on its way, it becomes of interest to re-examine the possibilities of the next stage of power-reactor development. This short article will therefore consider the outstanding properties of two more or less directly competitive types of reactor which have for a long time claimed the serious attention of nuclear engineers, namely, the sodium-graphite (Figures 16 and 17) and pressurized-light-water systems (Figures 15 and 18). Both these types require at least slightly enriched fuel, but both appear to be within striking distance of being developed into machines with a conversion factor close to unity. Both are intermediate in size, compared with the essentially large natural-uranium fueled gas-cooled graphite-moderated reactors, because of the cooling properties of liquid coolants and the fuel enrichment employed, but are large enough to be of interest for power station duty.

More highly enriched versions of these types having a smaller physical size and total power output would be of more interest for mobile applications and would not be economic for central-station electricity generation. Other types of highly enriched reactors such as the homogeneous aqueous solution and the heterogeneous bismuth solution types, although potentially economic, are somewhat further away in regard to technical development than the two types to be considered. However, it should not be assumed that the PW and SG types are the only contestants for the Stage II race, for such propositions as the Canadian heavy-water-moderated and heavy-water-cooled NPD reactor, using near-natural uranium, and possibly even gas or sodium-cooled heavy-water reactors have considerable merits of their own; the high-temperature gas-cooled graphite-moderated reactor is also, of course, a serious competitor.

For the present purpose, however, it is of interest to consider the SG and PW designs because fully-developed designs are available for each type, by good fortune, of approximately the same power rating, in the two Geneva papers P.493 and P.815. It is upon these papers that the comparative notes which follow have been based.

It is not intended to describe fully the design and construction of these reactors, which by now will

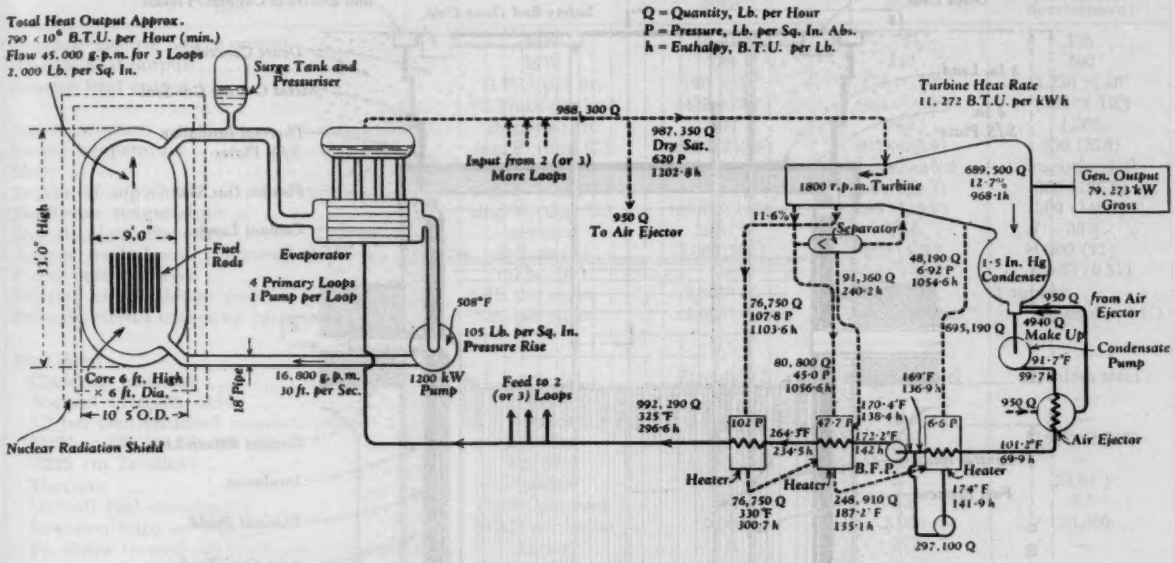

Figure 15. Diagrammatic layout of pressurized-water reactor and associated plant.

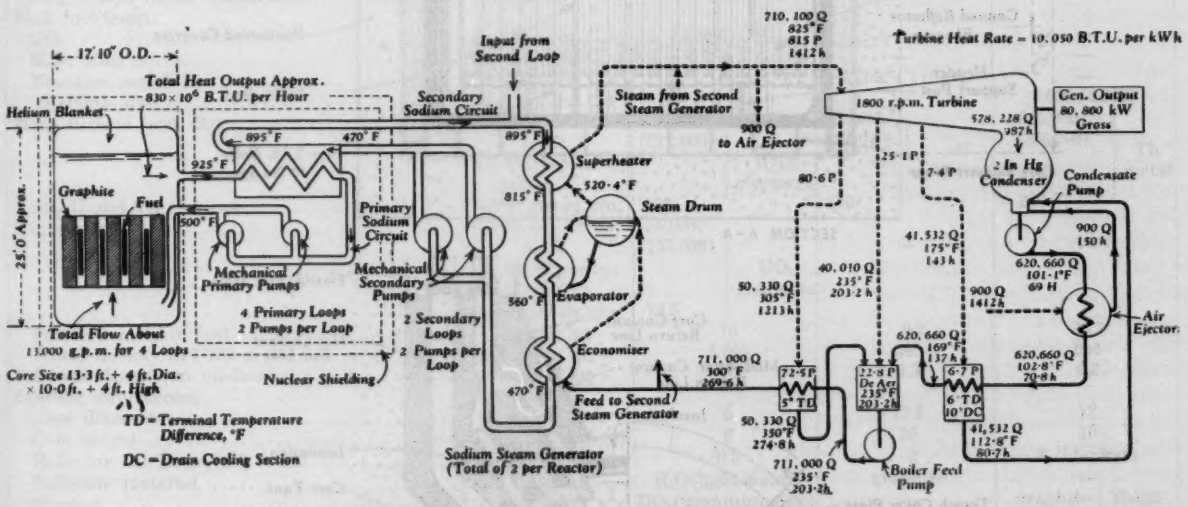

Figure 16. Arrangement of sodium-graphite reactor and power plant.

have become familiar from the Geneva papers and various survey articles. However, to remind readers of their main features the accompanying drawings of the core assemblies and heat circuit diagrams have been reproduced.

PW REACTOR

The important features of the pressurized-water reactor are that the coolant and moderator are both light water, and that the steam pressure and temperature are limited by the economics of containing high pressures, which considerations result in the working pressure of reactors of this type being limited to about 2,000 lb. per sq. in., to which corresponds a saturation temperature of 636 deg. F (335 deg. C). It is therefore necessary to keep the hottest point in any fuel element a few degrees below this temperature to prevent the occurrence of surface boiling.

The primary water from the reactor is circulated in four separate primary loops through four steam generator units. The highest available primary water temperature makes it necessary to supply the steam to the turbines in the dry saturated condition, there being no excess temperature available to provide superheat. This results in lowered thermodynamic efficiency as compared with superheater plants and also results in the formation of water droplets during expansion in the turbine with consequent blade erosion difficulty which, in the present design, is limited by appropriate hard facing of those parts of the turbine likely to be affected. This takes the form

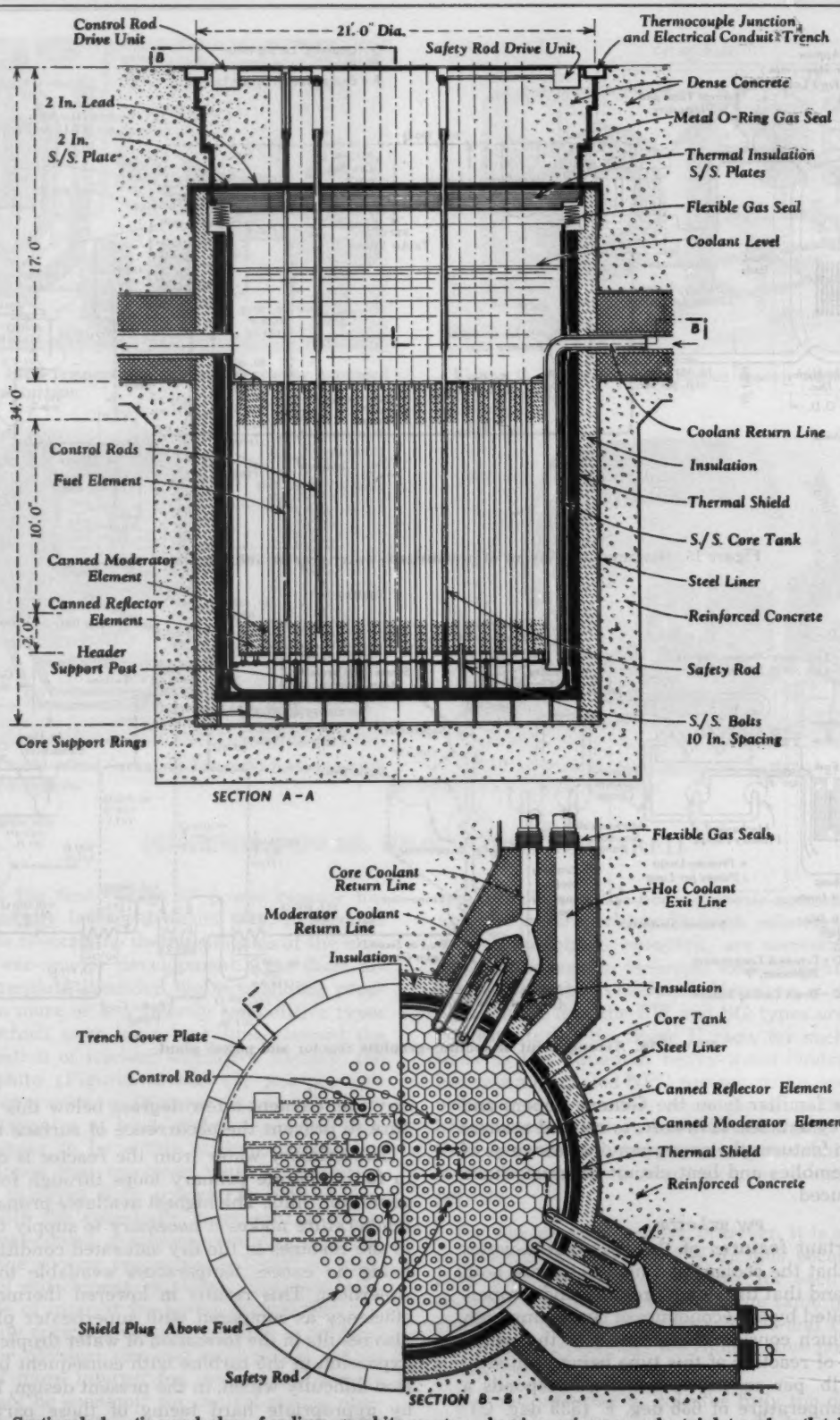

Figure 17. Sectional elevation and plan of sodium-graphite reactor, showing primary coolant inlet and outlet lines and arrangement of core.

TABLE VIII—*Comparative Data for Corresponding Pressurized-Water and Sodium-Graphite Reactors*

Item		PWR	SGR	SGR (future development)
Nominal electric power output	MW	60-100	75	125
Reactor heat output	MW	238	250	400
Reactor heat output	B.T.U. per hr.	790×10^6	830×10^6	$1{,}330 \times 10^6$
	(C.Th.U. per hr.)	(439×10^6)	(461×10^6)	(739×10^6)
Steam pressure	lb. per sq. in.	600	815	1,265,
Steam temperature	deg. F. (deg. C.)	486.3 (252.4)	825 (440.6)	950 (510)
State	State	dry sat.	superheated	superheated
Degree of superheat	deg. F. (deg. C.)		305 (151.7)	368 (186.8)
Feedwater temperature	deg. F. (deg. C.)	nil 325(163)	300 (148.9)	300 (148.9)
Overall plant efficiency	per cent	29.5 [1]	31.6	33.6
Approx. capital cost, per installed kW	dollars (£)	1,000 (357)	300 (171)	200 (71)
Power cost, per kWh	mills. (*d.*)	—	10.5 [2] (0.9)	6.0 [2] (0.51)
Primary circuit design pressure	lb. per sq. in.	2,500* [3]	approx. atmospheric [4]	approx. atmospheric [4]
Primary circuit operating pressure	lb. per sq. in.	2,000* [3]		
Fuel data:				
Cladding material	material	Zircalloy 2	stainless steel	stainless steel
Natural uranium oxide	tons	12	—	—
1.8 per cent enriched uranium metal	tonnes	—	24.6	—
U233 or 235 (in Th 232 alloy)	kg. (lb.)	—	—	518 [5] (1,140)
U235 (in Zr alloy)	kg. (lb.)	52 (114)	—	—
Thorium	tonnes	—	—	24.9 [5]
Overall fuel enrichment	fissile, per cent	1.1	1.8	3.7
Uranium burn up expected	MWD per tonne	3,000	3,000	10,000
Pu atoms formed per U235 atom burned (conversion factor)	factor	0.8	0.72	—
U233 atoms per U233 or 235 burned	factor	—	—	0.95 [6]
Fast fission factor (t)	factor	1.08	1.026	1.000
Max. fuel temp.:				
UO_2	deg. F. (deg. C.)	2,200 (1,204)	—	—
U/Zr alloy	deg. F. (deg. C.)	—	—	—
Uranium metal	deg. F. (deg. C.)	—	1,200* [7] (649)	—
Th-U233 alloy	deg. F. (deg. C.)	—	—	2,000 (1,093)
Max. surface heat flux	B.T.U. per hr. per sq. ft.	382,000 (U/Zr elements)	350,000 (U metal)	~640,000 [8] (Th metal)
	(C.Th.U. per hr. per sq. ft.)	(212,000) (U/Zr elements)	(194,000) (U metal)	(356,000) (Th metal)
U/Zr, U and Th elements	watts/per sq. cm.	120	110	~200 [8]
UO_2 elements	B.T.U. per hr. per sq. ft.	240,000 (UO_2 elements)	—	—
	(C.Th.U. per hr. per sq. ft.)	(133,000) (UO_2 elements)		
	watts per sq. cm.	74.5		
Power density in fuel	kW per kg.	10	9.2	23.3
Power density in U233 or 235	kW per kg.	1,500	565	694
Power density in moderator	kW per kg.	70	3.5	6.2
Leading dimensions:				
Core diameter	ft.	6	13.3	12
Core height	ft.	6	10	10
Reflector thickness, all round	ft.	0.5	2	2 (blanket)
Reflector material	material	H_2O (light water)	graphite	—
Blanket	material	UO_2 (uranium oxide)	—	graphite + Th232
Tank I.D.	ft.	9	17.5	16.2
Tank height	ft.	33	25	25
Tank thickness	in.	8½ + 0.25 s.s.	2	2
Tank material	steel type	carbon, lined stainless	stainless	stainless
Thermal shield:				
Thickness	in.	4	6	6
Inside or outside tank	position	inside	outside	outside
Material	steel	stainless	mild	mild
Coolant:				
Substance	material	H_2O (light water)	Sodium	Sodium
Pipework, etc.	steel	stainless	stainless	stainless
Primary inlet temp.	deg. F. (deg. C.)	508 (264)	500 (260)	510 (266)
Primary outlet temp.	deg. F. (deg. C.)	542 (284)	925* [9] (496)	1,025* [9] (551)
Secondary inlet temp.	deg. F. (deg. C.)	—	470 (243)	480 (249)
Secondary outlet temp.	deg. F. (deg. C.)	—	895 (480)	995 (535)
Max. pipe velocity	ft. per sec.	30	—	—
Max. velocity in core	ft. per sec.	20 [10]	9	25
Pressure drop in core	lb. per sq. in.	35	6	~100 [9]
Moderator cladding	material	—	Zirconium [9]	Zirconium* [9]
Max. temp. at coolant/moderator can interface	deg. F. (deg. C.)	—	950* (510)	1,050 [9] (566)

(See next page for footnotes)

of Stellite facing applied to the leading edges of blading wherever the wetness is greater than 6 per cent and the blade tip speed exceeds 900 ft. per second. The cylinder barrel, between rows of blades, will be lined with stainless steel applied by welding.

SG REACTOR

The sodium-graphite reactor has the great advantage of working at about atmospheric pressure, and the high outlet temperature of the primary coolant enables superheated steam to be supplied to the turbine. In fact, as will later be seen, if the sodium-graphite reactor type is developed so as to use thorium-uranium 233 alloy fuel elements it is likely that the thermodynamic performance of the plant will be limited only by the available steam-turbine technology. It may well be that this type of reactor would eventually be more appropriately coupled to a gas turbine rather than to steam heat conversion equipment.

Like the pressurized-water reactor design, this sodium-graphite design has four primary (sodium) loops, but it only employs two secondary sodium loops and associated steam generators. Both reactor projects are so arranged that the reactor can continue working with one or two of the loops out of service, thus giving the maximum flexibility of operation and at the same time providing for safety and reliability by the sub-division of the coolant circulation duty.

POROUS MODERATOR

A substantial disadvantage of the sodium primary coolant is that it becomes highly radioactive during its passage through the reactor core so that it is of paramount importance to ensure that no explosive reaction between the primary coolant and other materials in and around the plant can take place in any circumstances. A first requirement, therefore, is that the heat be transferred from the radioactive primary sodium to a circuit containing non-radioactive secondary sodium. This secondary sodium can then be used to raise steam, and in the event of a failure in the steam raising plant, any resulting explosion will not disperse any radioactive material. The use of a secondary circuit does not impose a heavy thermodynamic penalty. In fact in the proposed design there is only a 30 deg. F (16.5 deg. C) temperature difference between corresponding temperatures in the two circuits.

Another considerable difficulty in the SG reactor is the fact that the graphite moderator is porous and therefore has to be canned in zirconium to prevent undue absorption of sodium coolant, which would result in a high wastage of neutrons on account of the relatively high thermal neutron cross section of sodium. Zirconium is chosen as the cladding material on account of its very low neutron capture cross-section combined with satisfactory mechanical and corrosion properties. Arrangements must be made for cooling the highly rated graphite moderator and in the SG design this is achieved by leaving a clearance of about 1/10 in. between the moderator cans to permit an appropriate circulation of primary sodium past the cans.

CONVERSION RATIO UNITY

Whereas the maximum steam temperatures attainable with the pressurized-water design are limited by considerations of maximum practicable working pressure and surface and bulk boiling considerations, the maximum steam temperatures attainable in the sodium-graphite reactor are limited by the corrosion effects of sodium upon the zirconium. At the time that this design was evolved, progress in corrosion technology had indicated a maximum sodium/zirconium interface temperature of 950 deg. F (510 deg. C). It is worth noting in passing that if stainless-steel cladding of the moderator elements were employed, a maximum sodium temperature of 1,200 deg. F (650 deg. C) could be utilized now with correspondingly high thermodynamic efficiency in the heat conversion plant, but with resulting considerable losses in neutron economy. Metallurgical development work is expected to enable this limiting temperature to be raised for the sodium/zirconium combination, and in the fourth column of Table VIII are given performance data for an SG reactor of design similar to that of the PW reactor in column three, but which exploits this expected metallurgical advance and makes use of thorium fuel elements and a thorium breeding blanket. A slightly larger reactor is expected to have a conversion ratio of unity.

The other temperature limitation in the sodium-graphite reactor is more concerned with the maximum possible specific heat output from the reactor than with can temperatures. In the case of enriched uranium fuel elements proposed for the first design, this limitation is set by the alpha-beta transformation of uranium metal at a temperature of 1,220 deg. F (660 deg. C) with its accompanying volume change. It was therefore decided to limit the maximum fuel element center temperature to 1,200 deg. F (650 deg. C). This temperature limitation coupled with the low thermal conductivity of uranium metal, especially after prolonged irradiation, sets a limit to the diameter of fuel element which may be used for a given specific power output. It is again note-

FOOTNOTES TO TABLE VIII

* Means this item is a limiting feature in the design.
[1] Simple condensing cycle would have overall thermodynamic efficiency of 26.5 per cent.
[2] Based on free uranium 235 metal at 15 dols. per gram.
[3] Construction costs increase steeply above 2,500 lb. per sq. in. design pressure. Working pressure of 2,000 lb. per sq. in., corresponding to 636 deg. F (335 deg. C) saturation temperature, controls both maximum coolant temperature and maximum fuel-element surface temperature.
[4] Pressure approximately atmospheric, depending upon position in circuit; gas blanket would be at a few lb. per sq. in. gauge above atmospheric to ensure no inward leak of air, pump output would be several atmospheres, etc.
[5] Approximate derived figure.
[6] Expected that this would reach unity with larger reactor.
[7] Maximum uranium temperature limited by alpha-beta change point.
[8] Present limit of performance of zirconium in contact with sodium. Maximum zirconium/sodium interface temperature at present limited to 950 deg. F (510 deg. C).
[9] Expected attainable zirconium/sodium performance after development period.
[10] 20 ft. per sec. in uranium 235/zirconium (U235/Zr) alloy "seed" elements. 9.8 ft. sec. in uranium oxide (UO_2) "blanket" elements.

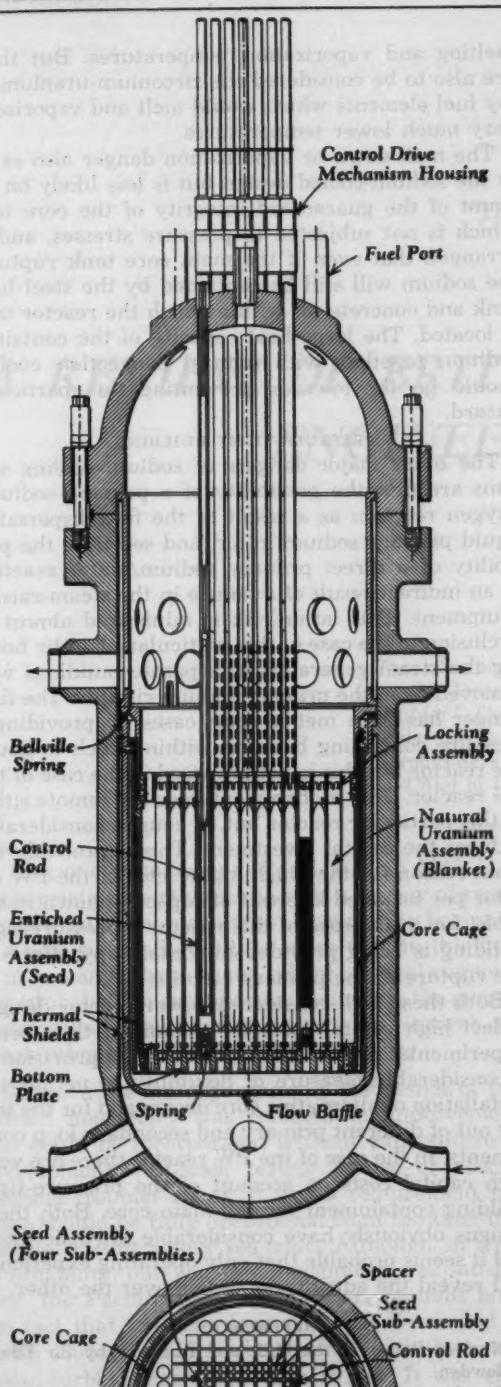

Figure 18. Sectional elevation and plan of pressurized-water reactor vessel and core.

worthy that if thorium-uranium (235 or 233) alloy fuel elements are employed the maximum fuel center temperature may be raised to 2,000 deg. F (1,090 deg. C), which would appear to put this reactor into the gas turbine class, although in the Geneva paper proposals this performance has been exploited in connection with a steam plant design with a resultant high overall plant efficiency of 33.6 per cent.

The choice of feedwater temperature (to the evaporators) and hence also the reactor inlet temperature for the primary coolant chosen in the two cases is of interest. In a coal-fired steam plant economy can be improved by raising the boiler feedwater temperature to about 400 deg. F (200 deg. C) by several stages of steam bleeding. But in a nuclear plant, which has a certain limited maximum coolant outlet temperature, this results in either less heat output for a given coolant flow or requires a larger coolant flow with correspondingly larger pumping losses, and larger steam generator costs, to which must be added the feedwater heating equipment costs. These considerations have led to the choice of 300 deg. F (149 deg. C) and 325 deg. F (163 deg. C) respectively for the SG reactor and PW reactor feedwater temperatures.

COMPACT CORE

Owing to the short characteristic lengths of neutron processes in water, the core size of a light-water moderated reactor, even of such low overall enrichment as in the case of the PW design, results in quite a compact core, in this case a cylinder approximately 6 ft. high by 6 ft. in diameter. Only a correspondingly thin (about 6 in. thick) neutron reflecting layer of water is required to surround the core, so that the internal diameter of the pressure vessel needs to be only 9 ft. The corresponding pressure-vessel wall thickness for 2,000 lb. per sq. in. operation is 8½ in. This vessel is fabricated of carbon steel with an internal stainless-steel cladding 0.25 in. thick to deal with the difficult corrosion problems presented by high-temperature, high-pressure water. Another peculiar advantage arising from the close spacing of fuel in light-water moderated reactors is the high fast fission factor (1.08 in this case) obtained as a result of fast neutron fissioning of uranium 238.

It is interesting to note that in the case of the pressurized-water design it has been considered advisable to provide a thermal shield inside the pressure vessel to limit neutron damage to the vessel. This thermal shield is of stainless-steel construction and the heat generated in it by the absorption of neutrons leaking from the core is removed by the coolant flow. Being unstressed, the thermal shield does not undergo serious radiation damage. In the case of the sodium-graphite design the thermal shield, in this case required to prevent excessive heat generation in the concrete biological shield, and consisting of interlocking steel slabs 6 in. in thickness, is placed outside the coolant containing vessel, which

is a stainless-steel tank about 17.5 ft. in internal diameter, and 25 ft. high. In the SG reactor the stainless-steel tank is 2 in. in thickness; in the PW reactor the stainless-steel lining of the pressure vessel is 0.25 in., to which must be added about 4 in. of stainless steel for the thermal shield. The rather surprising result, therefore, is that because of the large core volume of the SG reactor, consequent mainly upon the larger characteristic lengths for neutron processes in graphite as compared with water, the quantity of core container materials used in the construction of the low pressure sodium-cooled reactor is somewhat more than that required in the high-pressure water-cooled design.

COMPATABILITY

It is of interest at this point to consider the proposals for the fuel elements for the two reactors, and it will be seen that a very satisfactory degree of compatability has been achieved in the two designs. In the case of the PW reactor the major portion (12 tons) of uranium fuel is in the form of the dioxide which is quite inert to water at all temperatures and is manufactured by hot pressing and sintering to a high density followed by precision grinding; the fuel pellets so formed then being loaded into accurately made zirconium tubes to form fuel elements. The uranium 235-zirconium alloy fuel material is also satisfactorily inert to high-temperature water and if the bonded-on zirconium cladding of these elements should fail at any point it is not considered that there would be any serious release of radioactivity into the primary coolant water.

A similarly satisfactory situation exists in the SG reactor design. Here, the fuel elements are made of either slightly enriched uranium metal or of thorium metal alloyed with a small percentage of uranium 235 or 233. These elements are clad in stainless steel and a gap of about 0.010 in. is left between the fuel element and the can, this gap being filled with either sodium or sodium-potassium (NaK) alloy to act as a thermal bonding agent. Here again if the can ruptures, there would be no reaction between the fuel-element materials and the primary-coolant sodium although it seems likely that in this case there would be a greater release of fission products into the coolant than there would be if the can were directly bonded to the alloy fuel element as in the case of the PW reactor design. However, such a release would be of less consequence in this type of reactor because the primary sodium is in any case highly radioactive and already adequately contained and shielded.

SAFETY

With regard to safety, the major consideration in the PW reactor is the possibility of the sudden release of the stored energy of the pressurized-water circuits immediately followed by the melting or vaporization of the fuel elements, although in the Shippingport PW reactor design the bulk of the uranium fuel is in the form of oxide (UO_2) with very high melting and vaporization temperatures. But there are also to be considered the zirconium-uranium alloy fuel elements which would melt and vaporize at very much lower temperatures.

The melt-down or vaporization danger also exists in the sodium-cooled design but is less likely on account of the guaranteed integrity of the core tank which is not subjected to pressure stresses, and so arranged that even if the main core tank ruptures the sodium will still be contained by the steel liner tank and concrete pit within which the reactor tank is located. The large heat capacity of the contained sodium, together with natural convection cooling should go far towards preventing this particular hazard.

PRESSURE-TIGHT BUILDING

The other major dangers of sodium cooling systems are first the possibility of a primary-sodium/oxygen reaction as a result of the fine dispersal of liquid primary sodium in air, and secondly the possibility of a direct primary sodium/water reaction as an indirect result of a failure in the steam-raising equipment. This latter risk is minimized almost to exclusion in the case of this particular plant by housing the steam generators in separate buildings well removed from the primary sodium circuits. The first danger has been met in most cases by providing a pressure containing building within which to house the reactor but this is not proposed in the case of the SG reactor. This probably enforces the remote siting of this particular reactor but, of course, considerably reduces the capital investment. This is probably the main reason for the much higher cost of the PW reactor per installed kilowatt of capacity shown in the table, for in the case of this reactor a pressure-tight building is being provided to contain any effects of the rupture of the primary circuits.

Both these well-considered power reactor designs reflect high capital costs on account of their semi-experimental nature, which includes the provision of a considerable measure of flexibility to permit the installation of alternative core design and for the trying out of different primary and secondary loop components. In the case of the PW reactor there are very high capital costs on account of the pressure-tight building containment for the main core. Both these designs obviously have considerable intrinsic merit and it seems probable that only operating experience will reveal the advantages of one over the other.

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"THE SHIPBUILDER AND MARINE ENGINE-BUILDER"

A REVIEW OF BRITISH NAVAL PROPULSION ENGINEERING PROGRESS IN THE LAST TEN YEARS

ACKNOWLEDGEMENT

This abstract of the Twenty-first Parsons Memorial Lecture, was published in the December 1956 edition of "The Shipbuilder and Marine Engine-Builder." The lecture was delivered at Newcastle-on-Tyne in November 1956 under the auspices of the North-East Coast Institution of Engineers and Shipbuilders. The lecturer was Vice-Admiral Sir Frank T. Mason, Engineer-in-Chief of the British Fleet.

THE END OF THE Second World War, in 1945, is an appropriate time at which to start a review of recent progress in naval machinery, because the beginning of a new era really did take place then in this field, as in so many others. In the sphere of naval engineering, probably the greatest new factor was the general recognition of the need for money for research and the development of propulsion machinery.

Between the wars, progress in the design of propulsion machinery was confined to improvements that could be incorporated without expenditure on development, full-scale testing ashore or risk of teething troubles afloat. It was a requirement that ships should be fully operational from the time they completed contractors' sea trials. Although, in terms of reliability, our war-time machinery was satisfactory, the Pacific War, in particular, brought home the fact that the very long distances demanded by ocean warfare could not be steamed with the simple steam-turbine machinery then in use. It was clear that, if this country was to meet the challenge of the post-war world, a more adventurous development policy would need to be pursued. This, again, would require money and testing facilities, and the acceptance of teething troubles in the early days at sea. The recognition by the Government of the need to provide money for research and development in this as in other fields put upon the author's Department a wider responsibility. Resulting from our close co-operation with the United States Navy and our post-war examination of German naval developments, we had a wide background against which to view our future and compare our existing standards.

Looking back, it is possible to recognize two phases of development over the past ten years. It is also clear that here, in 1956, we are already embarked on a third phase. Of course, engineering development cannot be precisely defined and analyzed, despite our immutable aim of attaining the best solution to the naval-propulsion problem; this is because the naval problem itself is altered by the advance of the science upon which it relies for solution. Furthermore, development is a continual growth in which new and better machinery is evolved from that already known.

Phase I.—Development based on requirements learned from analysis of the Second World War and using engineering achievements up to 1950.

Phase II.—Development influenced by new armament fitted in ships combined with the requirements to face attack by nuclear weapons and using engineering achievements up to 1955; and

Phase III.—Development influenced by the use of atomic energy for propulsion using engineering achievements that can be reasonably attained by 1960.

THE MEANS OF DEVELOPMENT

The challenge of the post-war world led to an appraisal of the best method of developing the machinery of the future and for this it was clear that the Navy would need all the help available to it in the country. It also received a great deal of assistance from close collaboration with the United States Navy, which has continued throughout the years. The two mainstays of our policy, therefore, have been to depend upon industry to fulfill our needs, where necessary under development contract, and to go wherever we could to obtain the best answers to our problems. There are, however, certain fields where an item has no application in the commercial field and its development is not technically rewarding to industry. In these cases, it becomes necessary to undertake the work at Admiralty Research Establishments or, at times, in H.M. Dockyards. The primary function of these establishments, however, is testing and undertaking research into test procedures. The Engineer-in-Chief has at his disposal the Admiralty Fuel Experimental Station (primarily concerned with fuel-burning methods and equipment), the Admiralty Engineering Laboratory (primarily concerned with internal-combustion engines and gas turbines), the Admiralty Oil Laboratory, the Admiralty Distilling Experimental Station and the Admiralty Fire Test Ground. He also has naval wings at the National Gas-turbine Establishment and the Naval Aircraft Establishment, Bedford. A recent addition to these teams of naval officers and scientists has been the Naval Section at the Atomic Energy Research Establishment, Harwell.

In the somewhat special field of gearing, in which the fulfillment of naval requirements was dependent upon the improvement of production techniques not normally demanded commercially, special measures were taken, and the Admiralty-Vickers Gearing Research Association was set up. The Admiralty Development Establishment at Barrow was also started, to deal with special submarine-propulsion problems. From 1950, we have had also the Admiralty Oil Quality Committee (in permanent form, now the Admiralty Fuels and Lubricants Advisory Committee), which has marshalled talent from many quarters, not least the oil industry, to help us solve the increasingly severe problems of combustion and lubrication.

The need for facilities to test steam turbines for advanced conditions was met by the marine engineering industry setting up Pametrada in conjunction with the Admiralty, who have made continuous use of them, beginning with the testing of the main turbines for the *Daring* class, and continuing with the testing of complete machinery installations for A/S frigates and for the new advanced prototype machinery.

What we still lacked was the capacity to survey the whole world of engineering development, to enable us to pick and choose the best bits, and then to weave them into complete installations that really represented the best that the country could do. It was for this purpose that the Yarrow-Admiralty Research Department was set up. This team does not compete commercially in the design of any components. It has the task of studying the requirements for naval machinery as they develop and of investigating the feasibility of all the conceivable combinations of components that might fulfill them. The evaluations that result are designed to ensure that each class of ship has the most suitable installations that can be derived to meet its particular requirements and give the best possible performance within a minimum of weight and space.

THE FIRST PHASE OF DEVELOPMENT

During the years following the war, much consideration was given to the new shape and size of the Fleet which the Navy would have to achieve by new construction and conversion. One fact which seemed to be quite settled was that we should need a predominantly small-ship new-construction program, consisting largely of frigates and minesweepers. These would require long ranges, low machinery and fuel weights, and had to be easy to build and maintain.

The need for a large program of small ships with long range made the choice of machinery controversial. The Diesel-engine enthusiasts offered low fuel consumption; the gas-turbine enthusiasts offered exceptional gains in machinery weight and space; while those who studied developments in steam plants promised results in which reduction in fuel consumption and in weight and space would go together. The range of horse-powers required would undoubtedly cover applications for all three types. At the outset, the team formed by Messrs. Yarrow & Co., Ltd., and the English Electric Co., Ltd., working in the closest co-operation with British industry, were given the task of making a world survey of engineering practice in the naval, merchant-marine and power-station fields, in order to present the Admiralty with an assessment of how far each had progressed and what use could be made of this progress in the naval machinery of the future. They were given the particular task of studying the optimum steam plant of 30,000 S.H.P. that could be devised to follow quickly upon the *Daring*-class machinery. After this initial investigation, however, the English Electric Company withdrew entirely from the team, so that it could obtain turbine designs on a competitive basis from any firm.

The *Daring*-class machinery had been designed on the pattern of U.S. naval destroyer machinery, because we knew theirs had proved very satisfactory. It was the quickest way to produce ships that would be able to steam for equal ranges with U.S. warships in the Pacific War, and in 1944 it seemed more than likely that they would be needed for this.

This machinery had involved the introduction of

four simultaneous steps into fields that were new to us. The steam temperature was raised to 850 deg. F., and thus we entered the creep range; the boilers had two furnaces for superheat control, and although this type was being planned for the *Weapon* class, they were not then at sea; the gearing was double-reduction, which had been dropped in the 1920's by most people after a spate of trouble; and the turbine rotors were solid and of low-alloy steel. Technically, the last two steps were the most difficult to take and the most profound in their consequences. We were freed from the limit on steam temperature and rotor speed imposed by the shrunk joint of our previous h.-p. turbine rotors, and we were freed from a virtual limit of 10:1 turbine to propeller-speed ratio for cross-compound turbine sets. From this point, the turbine speeds adopted for any set of steam conditions were limited solely by metallurgical considerations for turbine rotors. Moreover, instead of being forced to design turbines for the maximum efficiency at about full power, we could bring the point of maximum efficiency down the power range, where we needed it more to give a large cruising range for a minimum of fuel. The two-furnace boiler was large and heavy, but, now that we had entered the creep range, why stop at 850 deg. F.? Now that we had double-reduction gears and the turbines had become so small and light, why not have more than two per shaft? These were some of the aspects that the Yarrow Admiralty Research Department was set to explore, in conjunction with members of the author's Department.

MACHINERY FOR THE NEW FRIGATES

It was while this study was proceeding that the need for new frigates of various types emerged. The accent was still on long steaming range and small ships. The anti-aircraft and aircraft-direction frigates were to be two-shaft ships with 8,000 S.H.P. on each shaft. No suitable steam design was available. The Admiralty Standard Range I. Diesel was under development and gave promise of being a good engine of low weight—about 17 lb per S.H.P. The installation, compared with those of our war-time frigates, was a great improvement and it was decided to engine these ships, therefore, with four A.S.R. I. engines geared to each shaft. Being a range of engines from six cylinders in line to sixteen supercharged cylinders in Vee formation containing mainly standard components throughout the range, the Diesel-generator engines, of which there are four, were also chosen from this range.

This was followed by a requirement for an anti-submarine frigate of about 30,000 S.H.P. on two shafts. The urgency was great and effort was diverted from the study of possible progress in destroyer machinery to this problem. The displacement of the ship was limited to achieve maneuverability, and this displacement could not be met unless the weight of machinery and fuel to achieve the long range specified was reduced by between 25 and 30 per cent, compared with war-time machinery, and a similar reduction made in the length of the machinery spaces. One of the interesting aspects of this was that it made weight of fuel and weight of machinery interchangeable. It was, therefore, worth adopting a less efficient unit, if it was so much lighter that it compensated for the extra fuel which its inefficiency would make necessary. The converse was also true; if a heavier machine or heat-exchanger would give added efficiency, to justify its use, it must save more fuel than its own weight in one voyage, assuming all fuel to be expended. Various adjustments were made after the shore test of a prototype plant, but, in general, the result of the experiment has justified the method adopted. The targets set were severe and the method of attack was the first attempt at a fundamental study, using every source of information in the country, leading up to final installation of the machinery in a ship. The design, known as Y.100, should be judged against this background.

This requirement was quickly followed by another for smaller A/S frigates that would be cheaper to build. It was decided to produce a single-shaft version of the larger anti-submarine frigate machinery, using the same main engines. The larger ship had only two boilers, and as no one would accept a single boiler in a ship, almost everything except the main engines and turbo-generators had to be re-designed. This resulted in a set of machinery of comparable horse-power in a somewhat similar ship to the two-shaft Diesel engine-driven frigates. It is known as Y.101. The steam version is superior on the weight and space occupied by the machinery and fuel and, of course, burns a cheaper fuel. However, a single-shaft ship cannot be compared with a twin-shaft, except after operational experience has been gained.

At about this time, the development of a gas-turbine engine for naval use showed promise of giving very good results for a coastal craft. This engine was being developed as the sole method of propulsion, to give good economy over a range from 20 per cent to full power. It was thought that an enlarged version might well provide a rival for both steam- and Diesel-engined frigates. A paper investigation was therefore instituted for a two-shaft gas-turbine installation of 7,500 S.H.P. on each shaft. The so-called R.M.60 engine of 5,400 H.P. has fulfilled its promise, and is now successfully undergoing a long series of trials in H.M.S. *Grey Goose* under various climatic conditions. It was found, however, that the attempt to scale up this design for a major ship installation was not such an attractive proposition, and it was abandoned.

STEAM MACHINERY FOR HIGHER POWERS

The effort to progress was now redirected to the original target of a 30,000-S.H.P. steam set as a suc-

cessor to the *Daring*-class machinery. This became known as the Yarrow-English Electric Advanced Design, since it was a continuation of the original development contract. The first of these designs, known as YEADI, was so planned that it lay within the experience of the component designers. The steam temperature of 950 deg. F. was selected as being within the experience already gained with land-boiler installations. The requirement for economy at low powers did, however, make the maintenance of this temperature necessary at low flows through the superheater, and this presented a particularly severe problem.

An extensive survey was carried out on the pressure level most suitable to various temperatures and for various types of ships. This resulted in the conclusion that the boiler pressure of 650 lb per sq. in. adopted in the *Daring* class was still close to the optimum for this power in destroyers, although, for greater power and larger ships with different characteristics, somewhat higher pressures offered some advantages. The gains, however, within the range of 600 to 1,200 lb per sq. in. are not very significant on a basis of overall weight of machinery and fuel. Other factors, such as the effect on steam catapults in aircraft-carriers, therefore, play an important part in the final choice of pressure for any given class of ship.

The YEADI prototype set is now running on test at Pametrada and marks the end of this first phase of development.

A stage has been reached in the increase of steam conditions where, for any further thermodynamic gains, the effort in terms of development cost is increasing rapidly, and the law of diminishing returns must be studied. There are problems of corrosion of metals at high temperatures caused by the products of combustion of oils containing sodium, vanadium, sulphur and even sea-water.

In this first phase, each component has been developed along conventional lines to a logical economical limit. Boiler sizes, which, in natural-circulation boilers particularly, depend on the size of the furnace, have been reduced by increasing the heat-release rate to the point where the advantages are offset by the increases required in blower power. Draft losses have increased to 50-in. in Y.100 and to 85-in. water gauge in YEADI. Turbine speeds have been pushed to the limit of strength of rotor alloy steels, which can be produced in a reasonable period. Gear loading has been taken to a point where full use is being made of the best surface-finishing techniques and the materials available.

SMALL CRAFT

The Deltic Engine.—

In parallel with the development in ships of the Fleet and escort vessels, there has been great activity in small-craft engine development. In the field of fast patrol boats, particularly, there have been developments in both gas-turbine and Diesel engines. A committee was set up in 1944, under the chairmanship of Sir Roy Fedden, to investigate the possibilities of light-weight Diesel engines, and from its deliberations the development of the Deltic engine emerged (Fig. 1). The development of this engine, to provide in the 18-cylinder version a horse-power of 2,500 at 2,000 r.p.m., with a specific weight of 5 lb per S.H.P., was undertaken under Admiralty contract and it is now in full-scale production, both for the *Dark*-class fast patrol boats and for coastal minesweepers.

The Gas Turbine.—

A gas turbine was installed in a motor gunboat in 1947 and ran successfully to give the boat its high speed, while internal-combustion engines were used for cruising. This was followed by the so-called G.2 gas turbines in the *Bold Pioneer* and *Bold Pathfinder*, which have done one series of trials and have now had Deltic engines installed as cruising engines. The R.M.60 (Fig. 2) is the first gas turbine to be used as the sole method of propulsion and has been very successful.

Figure 1. Deltic engines fitted in a "Dark"-class fast patrol boat, showing the opening required to replace engines.

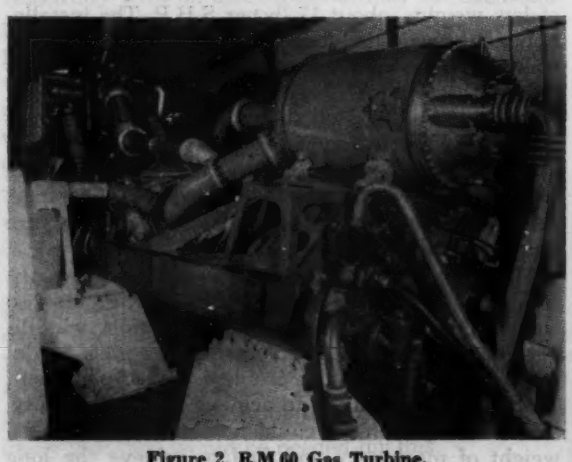


Figure 2. R.M.60 Gas Turbine.

The conclusions about the gas turbines are as follows:—

(*a*) *Cycles.*—The most important advantages offered by the gas turbine for naval service generally are:—

(*i.*).—Compactness and low weight;

(*ii.*).—Ease of maintenance; and

(*iii.*).—Great flexibility in operation.

It is now felt that probably these can be fully realized only in open-cycle engines of simple form with a minimum of heat-exchangers, ducting and general complexity.

(*b*) *The Design Approach.*—

Experiments have shown that it is best to approach the design of naval gas turbines using the light-weight aircraft engine technique, rather than to modify steam-turbine practice to cope with the rapid temperature changes and other problems involved.

The performance of simple gas turbines has increased with striking rapidity in recent years, a development aptly illustrated by the G. series of engines. In addition to the general development of propulsion gas turbines, a program of gas turbo-generators, from 100 to 1,000 kW. has been carried out (Fig. 3). Various small gas turbines for emergency fire pumps and boat propulsion have also been developed (Fig. 4).

THE SECOND PHASE OF DEVELOPMENT

While we have been struggling to produce the right sort of machinery for these types of ships, however, other developments in the spheres of nuclear weapons, of submarine detection, of radio and radar communications and of guided weapons, have profoundly affected the conception of the type of ship that we need to build. Add to this launchers for guided weapons, and the stowages and handling of the weapons themselves, and the proportions of the problem start to emerge. Moreover, the conditions of our day have produced the now familiar differentiation between cold, warm and hot wars. This new classification of types of war creates another problem for the naval staff in defining the conditions for which they wish ships to be designed. It once more alters the delicate balance in which the various needs for a ship design are weighed when the most desirable compromise is being judged.

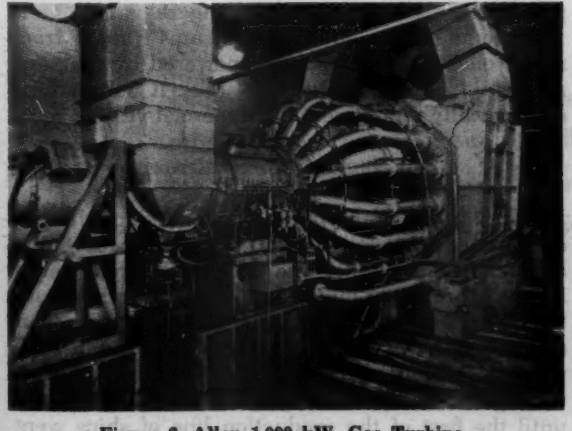


Figure 3. Allen 1,000-kW. Gas Turbine.

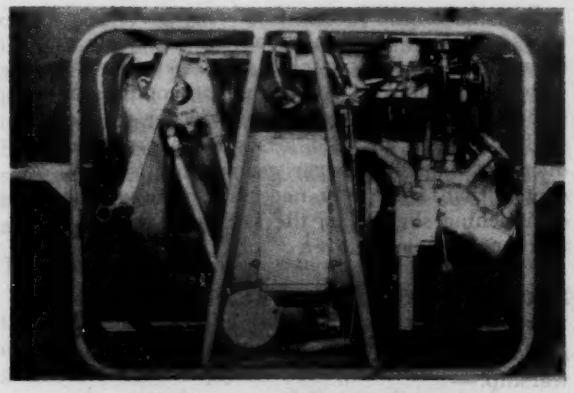


Figure 4. Gas-turbine Fire Pump.

The Boost Concept.—

The analysis of war-time and peace-time records showed that a warship needed to steam at maximum power for a relatively short period, so that the full-power component of any system could be designed for a medium life and thus permit light-weight scantlings. Following this line of reasoning, an idea of a base steam plant, which provided power for, say, 25 knots, boosted by gas turbines to give maximum power, was conceived. The result offers a wide radius of action under war-cruising conditions, with an acceptable fall-off in efficiency for the higher powers at which extreme radius is unimportant. A prototype plant is now in course of construction, and the gas turbines, and gearing with its clutches, will be tested ashore. A similar plant is being designed for a guided-weapon destroyer, and the first of the class will be available as a prototype for evaluation trials for a period of about one year. A simplified version is also being designed for a small frigate of the new building program.

This boost concept also has attractive features from the aspect of nuclear warfare. The boost conception is by no means the only solution to a compact machinery installation with low headroom but, pending experience, it does provide an attractive one.

One of the advantages of this type of combination is that, since there is an alternative source of power to the steam plant, it is permissible to reduce the number of stand-by units. In order to take full advantage of this, it is necessary to incorporate a reversing gear. This has given rise to many ingenious proposals, but it seems that nothing more simple and effective than a reversing train of gears can be devised. This train is being incorporated in the gearing train from the gas turbines and can be clutched in for emergency maneuvering.

One of the well-known disadvantages of gas turbines is the size of air inlet and exhaust ducts, and a depression on the air-inlet side has always been viewed with horror by gas-turbine compressor designers. In this case, however, in order to allow of slightly higher air-head losses in the air and gas ducts, a somewhat larger gas turbine is being accepted than is strictly necessary, at the price of encroaching slightly on the savings made by using this form of prime mover.

Protection Against Nuclear Attack

War introducing the use of nuclear weapons demands the following additional requirements of a warship:—

(*i.*).—That it may be able to leave harbors and anchorages at a few minutes' notice;

(*ii.*).—That it may remain at sea with little logistic and maintenance support for very long periods; and

(*iii.*).—That it may be capable of steaming without adverse effect through radio-active atmosphere.

The first aspect, the ability to get under way quickly, favors the Diesel engine or gas turbine.

The second requires rugged machinery that can continue to operate, albeit at reduced efficiency, with a high degree of reliability even though maintenance is neglected.

The gas-turbine boost concept meets these two requirements admirably, providing, as it does, a rugged steam plant which fulfils the needs of item (*ii.*) and a gas-turbine unit that can always be ready at short notice to meet item (*i.*). There are, of course, other solutions. An all-steam four-shaft ship can be equally suitable, although the maintenance requirement may not be so easily met.

The requirement to be able to steam through contaminated atmosphere presents some interesting problems. It appears to be essential to seal all spaces where personnel are operating. To this end, engine-room ventilation must be closed down and the air in the compartments recirculated to avoid an excessive rise in temperature locally in the vicinity of machines, particularly electric motors. Boiler air must be trunked direct into the boiler, or the boiler-room treated as a closed box capable of being operated from outside. The solution being adopted in warship design is to place the boilers within an airtight box and to provide an air-conditioned control room within or contiguous to the engine-room. The control of all essential machinery is effected from within the control room. This has required the development of remote-control systems and automatic watchkeepers on some machines, such as turbo-generators and distilling plant. One of the fundamental needs has been the development of burners with a very wide range of output to make remote or automatic controls of boilers feasible. This has been achieved successfully and the results of YEADI boiler trials have been very encouraging.

THE THIRD PHASE OF DEVELOPMENT

The third phase of development is that influenced by the use of atomic energy for propulsion. This development at present is not one demanded by a change in the naval problem so much as an opportunity to find a better solution to the present problem offered by the practicability of nuclear propulsion. Once one navy has changed to nuclear power, however, the whole tempo of naval operations may well alter, since the ships will be able to steam for weeks at high speeds instead of for only a few days. Any navy that is unable to do this will then be at very severe disadvantage, so the naval problem will in fact alter. To summarize the naval problem, there are ten main requirements:—

(*a*).—Reliability.
(*b*).—High endurance at cruising speed combined with a high top speed.
(*c*).—Low weight.
(*d*).—Small space, including height.
(*e*).—Ease of operation.
(*f*).—Ease of manufacture.
(*g*).—Ease of maintenance.
(*h*).—Resistance to shock.
(*j*).—Silence of operation.
(*k*).—Adaptability to automatic control.

Because the engineering for atomic propulsion is one of the offspring of the atomic bomb, strict security has overshadowed, and undoubtedly retarded, its development. However, its application to warships and commercial vessels remains almost wholly an engineering problem and one that can only be solved by the engineering industry.

Nuclear propulsion is immediately attractive for submarine propulsion and it was decided, therefore, that the first step should be in this direction. The prototype propulsion unit, which will consist of a pressurized-water reactor, heat-exchanger and steam turbine, is under development, and the first unit will be operated at sea when shore trials have been successfully completed. The engineering problems include those of heat flow in the core, shielding, pumping radio-active water at high pressures and temperatures without leakage, and the design of pressure vessels and heat-exchangers.

At some future date, all warships (apart from minor ones) will probably be powered by reactors, and as the cost of nuclear fuel falls, it will become economically attractive for commercial vessels.

THE FRUITS OF EXPERIENCE

The Need for Careful Planning.—

The phasing of the development and production of machinery installations requires careful study and realistic planning. The pace of development is high; the process of building naval ships in this country is slow. We cannot wait to get sea experience of a new type of machinery, modify it and then start to build the rest of the class. If we attempted to do this, the time from starting to design the machinery until the first of the production line of ships went

to sea would be, on present showing, about eight years. By then, the ship would be obsolescent.

Shore trials have proved very valuable in eliminating many causes of trouble in new installations where fundamental changes have been made to components or systems. On the other hand, they are very expensive. Installation, running costs and the costs of unpredictable delays mount up rapidly and discourage such trials unless they are essential to prevent later delays. It is not possible, however, to cover such things as propeller and shafting characteristics, and troubles have been experienced at sea after successful shore trials had given a sense of security. It follows, that it is still essential to get machinery to sea in a ship as soon as possible.

The Need for Manufacturing Excellence.—

Before and during the war, materials used were comparatively simple and the production processes straightforward. A field has now been reached where alloy steels and other alloys are essential in major parts like boiler steam drums, steam pipes and turbine rotors; they are used, of course, much more extensively in gas turbines and Diesel engines. Welding techniques for alloy steels and non-ferrous materials are increasingly important. Surface finish, hardening techniques and production processes generally have, in fact, become fundamental features of the process of developing new machinery. Gas turbines, free-piston gas generators, the Deltic Diesel engine, superhearters for high temperatures and highly loaded gears, to take a few examples, have all depended for their existence upon the development of suitable techniques to overcome difficult production problems. It is fruitless to undertake development unless production techniques can keep pace, and these have now become of paramount importance in all projects for meeting high machinery ratings.

There is a second reason of almost equal importance. The delays during the war from lack of interchangeability of parts resulted in ships remaining in harbor when they could have been on the high seas. The whole problem of availability of machinery is influenced by the standard of production. This includes the vital need for meticulous inspection. Errors in production are bound to occur, but if inspection is rigid, they can be corrected under the best conditions in the shops with all the appliances and experts on hand.

The Importance of Unconsidered Trifles.—

The reduction in size of the major components throws into high relief the minor fittings. Drain cocks, pressure-gauge valves, drain pipes, vent pipes, gland evacuation pipes, and gland-water sealing pipes—they are legion, and the tendency is to see more and more of them, with remote servo- and automatic controls now coming in to add to the host. Often a diagrammatic sketch is all the guidance the fitter is given. The result can easily be that machines, which looked accessible enough on a drawing or even in a scale model, are so hedged round with small cocks, valves and pipes that it is impossible to approach them at all, let alone maintain them, without dismantling the surrounding forest. Recently, it was found worthwhile to spend a considerable effort in studying the drain system of the *Eagle* and the *Ark Royal*, and it was demonstrated that the overall improvement in the maintenance effort required in these ships was out of all proportion to the small effort deployed on the redesign.

Cleanliness is at present another unconsidered trifle. For ships with remote-controlled or nuclear-powered machinery, almost clinical cleanliness will become a firm requirement. Much can be done, and is being done, in the design and manufacturing stages to ease this problem, but eventually it rests with the people who install the machinery to ensure that it is achieved in practice.

Two 4800 h.p. gas turbines have been ordered by the U.S. Navy from Metropolitan Vickers of England. Installation is planned for the two inboard shafts of the PT 812 for trials and evaluation. The outboard shafts will retain the presently installed propulsion units during the trials.

THE UNTIED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.
Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

CAPTAIN R. E. W. HARRISON, USNR, Retired

MODERN MARINE PROPULSION GEARING

THE AUTHOR

was born in Manchester, England, in 1893. Educated Manchester College of Technology. With Royal Engineers, British Army 1914–1919, Egypt, Gallipoli, Sinai, France, Belgium. Industrial Engineering experience includes special apprenticeship and supervisory positions with Churchill Machine Tool Company, England, in the building design and engineering selling of precision grinding machinery; in 1926 as Director of Engineering, Cincinnati Grinders, Cincinnati Milling Machine Company; 1934 Chief, Machinery Division, U. S. Department of Commerce; 1935 Vice-President Chambersburg Engineering Company; in World War II, on staff of Assistant Secretary, U.S. Navy, and later as Special Assistant to the Under-Secretary; Registered Mechanical Engineer in Ohio, New York, Pennsylvania, Maryland and District of Columbia. Fellow ASME and Royal Society of Arts; Member other Engineering Societies in U. S. A. and Europe. At present engaged in Engineering and Management Consulting, Washington, D.C.

INTRODUCTION

A PENETRATINGLY critical review of the engineering progress achieved during the last fifty years in the processes involved in converting the fuel aboard ship into propulsion of that ship, for a given distance at required speed, clearly indicates that the progress, while spectacular as a whole, is, without doubt, sketchy in spots.

Marine boilers today are, size for size, many times as efficient as they were fifty years back—likewise, the turbines for which the boilers provide the steam. Horsepower for horsepower they are also much smaller and lighter.

Shafting which transmits power to the propeller is proportionately lighter in terms of pounds weight ratio-wise to delivered shaft horsepower, and propellers, in turn, are much more efficient than they ever were before.

Right in the middle of this line of power transmission sits the gear case, all too frequently the location of deep seated troubles, and the only remaining major point of weakness in a ship's propulsion power transmission line.

This paper discusses the reasons for the existence of the current propulsion gearing problem, and poses some suggested remedies.

SOURCES OF REALLY FACTUAL DATA

As is customary in the development of most, if not all, major mechanical units and power generation mechanisms, new elements in the power transmission line are first put through shorebound laboratory tests, designed to evaluate performance in terms of designed for and specified requirements measured against actual results.

Of necessity, laboratory tests are limited in time, and frequently are run under ideal conditions, and while these tests are obviously necessary, it is nevertheless true that the only really reliable engineering data are these forthcoming from "milkrun" operation at sea, year in-year out, on strict time schedule and in accordance with a set of rigidly required conditions of operating economy.

Possession of a powerful fleet of armed vessels seldom, if ever, provides "milkrun" type of engineering experience data, for the very reason that military operations by their essential nature are invariably, even in peacetime, on a fire-run basis.

Fighting ships to win the fight must be capable of extraordinarily fast maneuvering, plus bursts of speed far beyond anything commercially obtainable or even necessary. While every endeavor is made to operate under standard speed conditions as frequent-

ly and for as long as possible, tours of ship's duty are necessarily erratic and relatively so short, that engineering data which can be culled from the logs are so beset with special conditions and variables, that they cannot compare in operational validity with the carefully kept records of, for example, the operation of a fleet of tankers sailing between some port in the Caribbean, and a destination in the Delaware River. In other words—a "milkrun."

It could well be debated that a military ship seldom, if ever, jeopardizes its ability to perform its designed mission by failing to achieve a proper economy of operation, because perhaps the propeller makes ten more or ten less turns per minute then called for as the designed operational speed (standard), but should a tanker on a "milkrun" be compelled for some machinery shortcoming to operate at ten less RPM than designed, it will quickly become apparent that this ship so handicapped is unprofitable. There then comes into play the strong commercial urge—in fact the urgent necessity to build up the efficiency of this "milkrun" performance to the point where profit is consistently assured (at an economic maximum). The alternative is to lay her up.

The net of the discussion up to this point is that there is much to be learned for the benefit of designers of military ships from the performance of vast tanker fleets, most if not nearly all of which operate on a "milkrun" basis, and thereby produce some priceless engineering data for the discerning designers of ships. The ferry boats in the North Atlantic, and Pacific ferry services also, yield excellent engineering data, but passenger service persists and necessitates overdesigns which detract from the values, from the designers' viewpoint.

Only those Naval Architects, who sweat out all the numerous and always conflicting factors which have to be accommodated to produce a given speed at a predetermined fuel economy, can fully appreciate the complexity of the engineering problem, when this problem relates to a strictly military ship of the Destroyer class, where engine room cubic footage is always at a premium.

The burden of providing a usable engineering solution can, and already has been demonstratably eased by the emergence of nuclear power, which largely removes the present overriding considerations of fuel economy. However, nucleonics as a source of power for a majority of units of the U. S, Fleet and its train is a long way off.

In the interim we can do none other than get all the "calories" we can out of the fuel oil and provide a mechanism reaching all the way from the bunkers to propellers, which translates calories into reliable standard speed, a spectacular maximum speed, maneuverability, and freedom from the apron-strings of a Naval Operating Base or a Naval Shipyard.

Any experienced researcher will testify at short notice that the data he feeds to the design engineers are most prized in proportion to their demonstrated reliability. Where, therefore, can the team of researchers and design engineers turn with more confidence than to the tanker operator who makes or loses a profit on his operations in terms of total available designed propeller turns per annum?

RATIOS

It is just as simple as that. Seagoing experience being what it is, cannot with impunity be ignored, and seawater being what it is, says that too much rotational speed on the wheel means cavitation and all the evils which go with it.

So—until there be developed an alternative to the 3, 4, 5 or 7 bladed propeller, to avoid cavitation and uncontrollable vibration, we must use relatively large diameter, relatively slow speed propellers (at least as slow as we can operate them, consistent with performance of the required mission of the ship). Tanker, Destroyer, Passenger ship or Carrier, spin the wheel too fast and we have cavitation and loss of efficiency.

The net result of this set of conditions and requirements is high ratio reduction gears, because turbines (steam and gas) work best at the higher RPMs and the wheels do best at the lower end of the scale.

Relatively high RPMs at the turbine, and low RPMs at the wheel, mean high mechanical leverage on the wheel, all of which is used to the good except that 10 revs per minute lost on a 100 RPM wheel (maybe because the propulsion gearing has to be "nursed") means 10 per cent extra time at sea with its accompanying dollar drain. Under such conditions one full year's operation is only equal to eleven months at designed speed. In other words, on a non-military ship it is the ship operator's profit which has gone down the drain.

Net of the foregoing: slow turning propellers, while good in the engineering sense, make significance of a few lost RPM disproportionately costly in terms of operational success.

SIGNIFICANCE

On the basis that it is the success, or otherwise, of our domestic economy which determines the type and size of naval power we can exercise or afford, is it not logical that just as the "milkruns" of the airlines give us exceptionally reliable data on plane designs, so the experience of civilian seagoing industry, in this case mercantile tanker shipping, can automatically provide excellently reliable design and practice bases for the *paralleling factors* in operational requirements for a fighting fleet?

ORIGIN AND PRECEPT FOR A BETTER TECHNIQUE

There are, of course, other commercial engineering achievements which point like beckoning signposts to those who seek a superior engineering performance in ship propulsion gearing, and it is extremely significant that this superior performance has been developed in a country which possesses no fleet at all, military or mercantile, i.e., land-locked Switzerland.

STRANGE PROVING GROUND FOR A BETTER CONCEPT

The geographical and topographical features of Switzerland inevitably are such that railroading and street-car services called for superlative performances to enable power units to pull vehicles up very steep grades, and necessity being forever the mother of invention, it was far from unnatural that Swiss machine tool engineers should devise a product and a method of gear production adequate to deal with their local situation. (The mountain goat may be tough to eat—but his steel-spring muscles and vitality are the envy of the world).

Hardened and ground precision gearing has been an accomplished *necessary* practice on Switzerland's railroads and street car routes for at least thirty years, and out of the failures and refinements of this experience has grown a gearing technique, proven throughout the civilized engineering world, never adequately copied and still supreme after many years as the best performer. This is the Swiss type gear train, case-hardened and ground throughout, with superlatively, accurately spaced gear teeth, true tooth form, and above all complete uniformity of mating surfaces automatically guaranteed by a unique system of grinding wheel wear compensation, which guarantees that the last shall be like the first —something which is *unique* in gear teeth.

RIGIDITY EXISTS ONLY IN MEN'S MINDS

The amateur engineer invariably starts out with the supposition that the structures he designs are rigid. The facts of life say that no greater delusion exists, and none is responsible for quite so many errors. This shibboleth has wrecked more mechanisms and engineering reputations than almost any other cause.

The astute designer of machinery knows that absolutely nothing on this planet is rigid, and every element in the basic design must, of necessity, be assumed to distort under load. Furthermore, if the mechanism is to function properly and survive, distortions must be calculated, checked by practice, and adequately compensated for under *all* operating conditions.

Competent machinery designers must be experienced physicists as well as mechanical engineers, and the best invariably design load distortion compensators into their mechanisms, so that under load, all distortions are catered for to the point where their evils are eliminated.

Even though propulsion gear trains and their gear carrying shafts be drawn and specified in accordance with best machine shop practices, as well as best materials and heat treatments available today, under torsional loads shafts will inevitably bend away from the point of maximum load to greater or lesser degree. Furthermore, the gear teeth will wind up and, unless these deformations are catered to in the machining as well as in basic design, the gears will never function as the designer hoped they would perform.

EVOLUTION AT WORK (ENGINEERING TYPE)

It was partially recognition of these features which led to the use of double helical gearing, with its over-designed static strength and its very own built-in, overdesigned, self-destructive forces (products of all the machining variables and metallurgical inconsistencies).

The dynamic destructiveness of a jack hammer is relatively child's play when stacked against the dynamic hammering that the most minute inaccuracies in a conventional double helical gear and pinion generate under all stages of work loading. During a properly instrumented test these minute but deadly hammer blows always show up as high and dominant peaks on the recording oscillograph and tape.

Single helical gears as produced today are a necessity, but with small helix angle, narrow face, fine pitch, small diameters, it is possible to provide proper tooth engagement and overlap, super-accurate tooth spacing, torsional wind-up compensation, tooth flank surfaces with fine micro-inch finish and tip and root relief. We have in the modern, relatively narrow faced, case-hardened and ground gear, the quintessence of hard won experience of those* who make gears by the million, as against the relatively few units required by the shipbuilding industry.

It must be conceded that this hard won efficiency carries a superlatively high commercial reward for success in the solving of the problem, and while the competition in this particular commercial race is such that there are today but three survivors out of a field of thirty—those same three survivors rank pretty close to the top of the scale as the Nation's great profit earners.

INERTIAS CAN BE COMMERCIAL AS WELL AS MECHANICAL

Why then do we perpetuate the gear trains of World War I and continue to insert costly, oversized monumental units of low efficiency in a power train which reaches from the oil bunkers with vastly improved efficiency all the way down the shaft tunnel to the propeller?

As one might expect, the answer is simple. Compare the specialized automobile industry profit experience with the wide-range financial ups and downs and relatively meager profits of the commercial gear industry, and we have the one most important and revealing key to the answer.

Technological progress thrives on profit, and it is the promise of reliable profit which motivates progress. The few hardy souls who persist at the invention game simply because they love it, are few indeed, and mostly financially short-handed.

THE RUB

We cannot, of course, drop the subject at this point and accept the marine gearing industry which is weighted down by its oversized, double, helical bull gears as held fast on a lee shore for the simple but all important fact that U.S. national survival depends

* The automobile industry.

not only on command of the sea lanes, but also on better performance than the submarines of our nearest military competitor, the USSR.

It is significant that the U.S. Government is currently spending $3-billion per year on research and development for the simple, single reason that commercial successes come too slowly and too erratically, to insure continuity of design progress in the military equipment field. Costly experience has shown that military invention, while patriotically stimulated during wartime, languishes in peacetime and all too frequently dies of that right common disease known as profit anemia.

Generally, during both war and peace, there is an eager seeking by manufacturers and commercial laboratories for U.S. Government Research and Development contracts, even though those who take them know that any profit for manufacturers is well in the future. Research and Development, as such, is a costly experience in the *immediate* profit column. This applies with particular significance to the generation of new and better military equipment designs (which includes propulsion gearing for fighting ships).

Where the desired improvement is a matter of a superior processing only, the experience is generally less costly to both the government and its researching contractor. Procedure is relatively simple. Government buys equipment and selected contractors do the work. When the new process is deemed of proven merit, the equipment is either mothballed or sold or rented to the user. In any case, the U.S. Government can chalk up an advance in production technology and for the time being satisfy itself that as far as that particular item is concerned, "M" Day is well taken care of.

FOREIGN NAVIES SOMETIMES TAKE THE LEAD

Governments of Britain, Canada, France and Germany have long recognized the commercially non-profit-feasible angle to military marine propulsion gearing, and of their own farseeing volition have equipped their principal gearing suppliers with special machine tools and collateral equipment needed to produce the type of gearing which is militarily necessary in ships of war and their trains, as well as commercially desirable in the mercantile marine, which, when war comes, automatically becomes the largest part of the supply train.

CONCLUSIONS

Most engineering progress is evolutionary and very seldom, indeed, revolutionary, notwithstanding claims of some professional advertisers whose main stock in trade is adjectives of superlativity.

A propulsion gearing problem, when licked, always seems a simple, logical, soundly professional piece of engineering reasoning, and most everyone figures that the solution was easy (after the event) and never stops to inquire as to how many professional casualties occurred as the problem walked through Gethsemane up and onto its eventual triumph.

Long life, highly efficient, economically priced, propulsion gearing is no exception, and if in this day and age we have prototype Carriers in dock with broken gearing, Oilers limping along at 90 RPM on the wheel instead of 110, and industrial machinery, such as highly expensive rolling mills, down for one week out of four because of inadequate gearing, this then is the mechanical engineer's Gethsemane and he may rejoice that he has been privileged to live through a time when an approvable solution to a great problem can be generated.

PHILOSOPHIC CONTEMPLATION IS OUT (THERE IS TOO MUCH HEAT ON)

There is too great difference in real values between philosophic contemplation of a situation which means only loss of dollars if voyage delay is prolonged beyond reasonable limits as against physical and moral loss in seamen's lives and sinking of valuable ships and cargoes during a war.

Two long World Wars within one short lifetime, plus valuable lessons in how to transport seaborne loads during the Korean Police Action, prompt the thought that handicapping of naval ships and their trains by the use of gearing other than that which is best in design and materials, is, indeed, costly folly, even though the peacetime commercial profit solution to the problem is still not in sight.

All of this definitely takes both naval combatant and auxiliary ships out of the strictly competitive commercial gearing field, and puts them in the same class as projectiles, guided missiles, torpedoes, and aerial bombs as far as required engineering qualities are concerned. Lets have a competitive commercial solution, if one is available *now*—but a solution is overdue and mandatory.

FORCE MAJEUR

Equally important, a sagacious military must, of necessity, generate in its suppliers' plants that technique and productive capacity which a normal competitive situation has been totally unable to produce.

The current international crisis brought on by seizure by Egypt of the Suez Canal properties seems likely to increase time at sea of all ships in the Eastern trade by 30 to 50 per cent—all of which adds up NOW to increased emphasis on higher practicable standard speed and need for superior reliability in the propulsion gear train.

A POSSIBLE SOLUTION

Triple, in lieu of double, reduction gearing will demonstrably greatly expand the procurement potential and can promptly remove one of the greatest of our national hazards in the event of another major conflict. Great emphasis is today placed on the dispersal of important production facilities. If we were irrevocably tied to double helical gearing designs, it would be found that the few manufacturers who

could make the large diameter gearing involved would all be within a 30 minute flying radius in a modern jet propelled enemy bomber. Obviously this represents the quintessence of wartime procurement vulnerability.

On the other hand with gear sizes limited to a maximum of 60″ diameter, the dispersing of facilities would be trebled and the availability of manufacturers increased tenfold.

Equally obviously, such broader basis of procurement would improve the competitive position in both war and peacetime to the point where the cost to the government of the mechanisms under discussion can be greatly reduced.

EXPERIENCE (THERE IS NO ADEQUATE SUBSTITUTE)

It seems proper to conclude this article with the remarks of a famous gear engineer,* who has devoted many years of intensive study to this subject. In his own particular field (gearing) he has a reputation for hardheaded engineering logic, which has spelled success and profit to his Corporation (the largest in the world).

The designers and builders of conventional ship propulsion gears, whether intended for warships, cargo ships, coast guard or tugs, are quick to defend their products against attack. One favorite argument is their supposition that modern automotive and aircraft gears are designed for limited life. This is sheer nonsense and merely reflects an affect of their cloistered life. Other "can't-be-done" arguments are equally invalid.

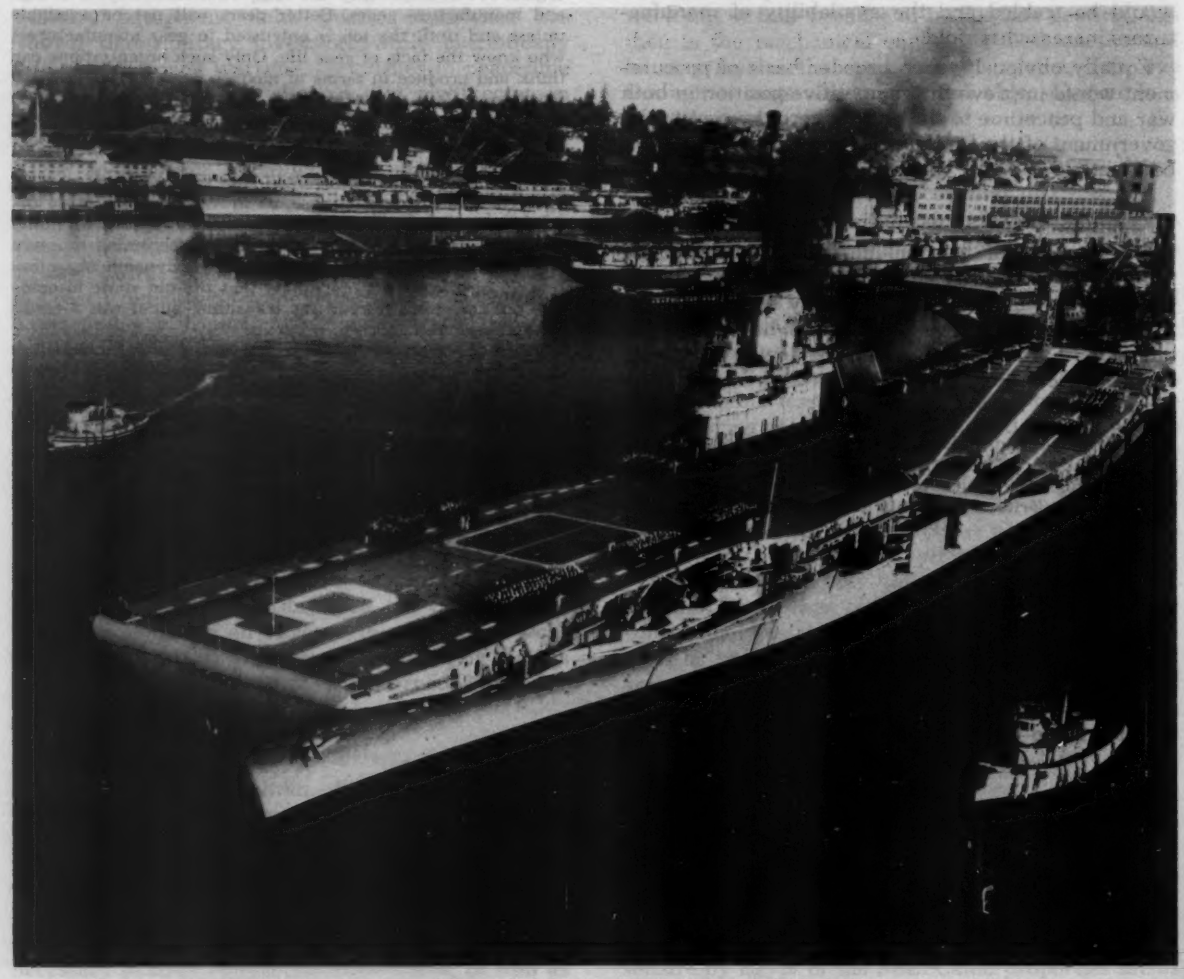
Progress in the development of small, light and relatively inexpensive ship propulsion gears cannot be expected as long as the development programs are based upon competitive designs prepared by the old, regular suppliers because these organizations know only the long outmoded way to design and manufacture gears. Better gears will not be available unless and until the job is entrusted to gear manufacturers who know the facts of gear life. Only such organizations can think and produce in terms of modern hard surface, narrow faced gears. It is up to the large purchasers to say how long we must plod along with outdated gears while the remainder of the ship, particularly in the Navy, is as modern as yesterday.

A similar situation confronted our railroads a few years ago. The remedy in that case, as in many earlier static industries, is familiar to all of you. In a few years the antiquated, inefficient steam locomotives are becoming museum pieces because the job was taken over by a dynamic organization. It is, of course, unfortunate that the old static locomotive builders were hurt in the transition, but it was a result of their own resistance to progress.

There are many gear manufacturers who are competent and ready to do for ship propulsion gears what has already been done for locomotives. There is, however, an important difference. The potential locomotive market was great enough to warrant private expenditures for the necessary research and development period prior to marketing the new product. It is doubtful that the potential market for ship propulsion gears can justify private research and development. This initial outlay must be assumed by a government agency through a contract to an up-to-date gear manufacturer.

* J. O. Almen

The 200 inch gear hobbers at General Electric's Lynn plant hob gears of up to 200 inch diameter, 88 inch face width, and weighing up to 144,000 pounds. Despite the enormous size and weight involved, tooth-to-tooth spacing variations of less than 0.0002 inch are maintained. An electrical device sets off an alarm if the gear should shift as little as one millionth of an inch during hobbing.



The USS *Lexington* (CVA-16) steams out of Puget Sound Naval Shipyard, Bremerton, Washington, on her trial run in Pacific waters following a two-year conversion and modernization which included the addition of the angled deck and hurricane bow, clearly visible in this photo, as well as steam catapults, improved type pri-fly, heavier arresting gear, and the all-aluminum deck-edge elevator. Also visible in the photo (left to right) are the carriers *Franklin D. Roosevelt*, first *Midway*-class carrier to be converted at Puget Sound, and then nearing completion; the USS *Midway*, newly arrived to begin a two-year conversion; and the USS *Yorktown*, an *Essex*-class carrier just completing a 7-month availability for a "baby conversion" including the addition of the angled deck and hurricane bow. The *Yorktown's* two-year conversion had been completed in early 1953—the short conversion was scheduled to add the latest improvements in carrier design.

"THE MARINE ENGINEER & NAVAL ARCHITECT"

Y.E.A.D-1—A NAVAL RESEARCH PROJECT

ACKNOWLEDGEMENT

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WAR EXPERIENCE during the years 1942 and 1943 indicated that destroyers of the United States Navy were capable of much greater endurance than those of the Royal Navy.

In order to improve the performance of our destroyers, the combined efforts of firms concerned in marine and land practice were devoted to the design of naval machinery. The results of their collaboration led to the *Daring* class, which represented a considerable advance on former practice.

It will be recalled that the eight ships of this class were fitted with three different types of steam turbines, five of Pametrada design, two of English Electric design and one with a B.T.H. H.P. turbine and Pametrada L.P. turbine design. Yarrow & Co. built the pair (*Diana* and *Decoy*) which had English Electric-type machinery.

During 1946 it was decided to consolidate the technical advances incorporated in the machinery for the *Daring* class destroyers. At the instigation of the Admiralty, Yarrow & Co. Ltd. set up Y-A.R.D. (Yarrow-Admiralty Research Department), a self-contained branch of the company with its own offices to handle development work on machinery installations. Y-A.R.D. operates as a design office somewhat on the lines of the engineering departments of the major marine consultants in this country and America to collaborate with main and auxiliary machinery contractors. It is able to produce complete machinery studies ready for production by other manufacturers. The Y.100 machinery for the present series of frigates now under construction was developed by this department, the prototype plant being erected at the Pametrada Research Station, Wallsend, for exhaustive shore trials. Such machinery is now being constructed by many engine-builders throughout the country for installation in the 12 *Blackwood*-class (single screw Y.101 sets) and the six *Whitby*-class twin-screw frigates. It is also being used in the current Canadian twin-screw frigate program, and a follow-on program of *Whitbys* has recently been initiated in the United Kingdom.

NOT A SEA-GOING INSTALLATION

The subject of the present article differs entirely from the machinery mentioned above as it is not a production set and is not intended to be installed afloat, although all the details are in line with future sea-going requirements. Y.E.A.D.-1 is essentially a trial horse on which the most up-to-date practice can be applied and examined. This machinery was one of the most important items to be seen in the test house during the 1955 Pametrada Open Week.

Among the features of the installation are the "boxed" Selectable Superheat boiler, high-speed all-impulse turbines, and a gearcase carried at three support points and having exceptionally high tooth loadings.

The possibility of future vessels having to withstand attack by thermo-nuclear weapons has not been overlooked and the machinery has been designed for remote control from a special compartment in such an eventuality.

BOILER

The boiler is of Babcock & Wilcox two-drum Selectable Superheat integral furnace type and was manufactured at the company's Renfrew works. It is designed for a drum working pressure of 700 lb. per sq. in. gauge and a final steam temperature of 950 deg. F.

The "boxed boiler" arrangement which has been

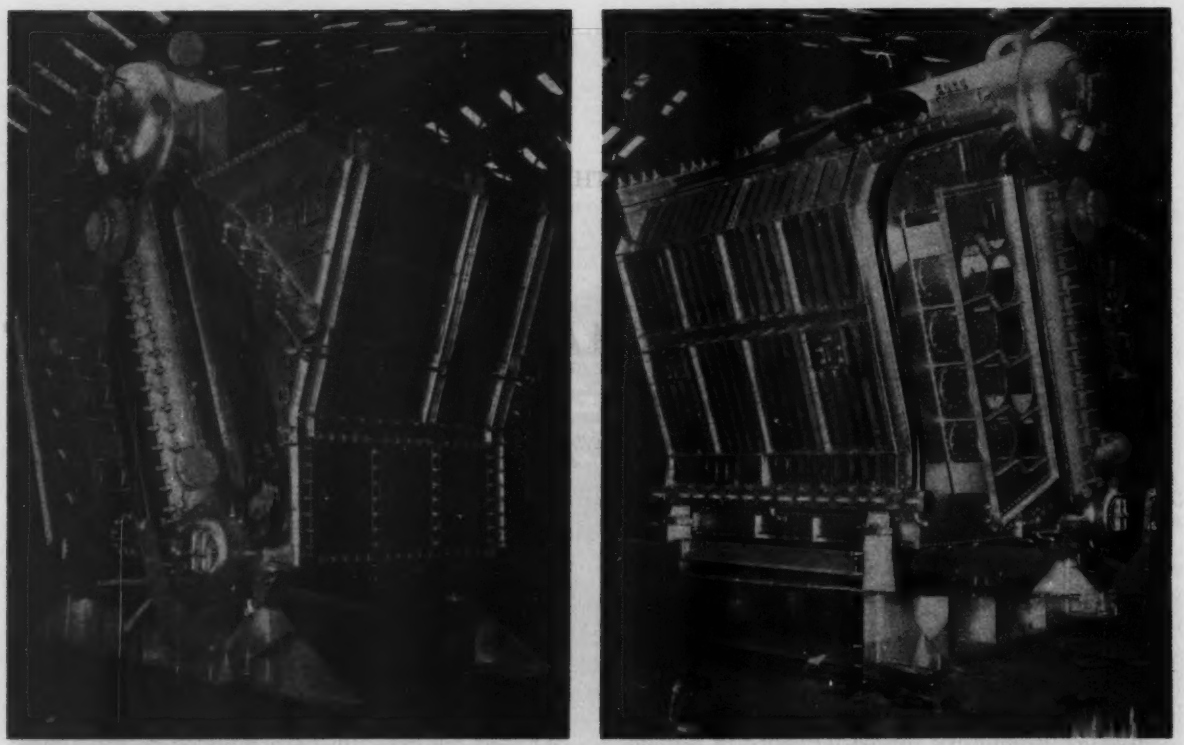

Figure 1. The Babcock Selectable Superheat boiler for Y.E.A.D-1, believed to be the highest-rated marine unit in the world, is seen partly erected at Renfrew. External down comers, seat for the economizer and water wall headers are shown.

adopted is one where, in an actual marine installation, the outer casing would be formed by the wing and transverse bulkheads of the boiler room.

The oil-burning equipment was designed and supplied by Joseph Lucas & Co. Ltd., Birmingham, and consists of nine spill-controlled burners arranged in two groups of four, with one as spare. These have a turn-down ratio (maximum to minimum output) of about 15 to 1 and are carried in Admiralty "suspended flame" type registers. The standard sprayer tips each pass 3,750 lb. per hour of oil (viscosity 60 secs. Redwood No. 1 with a manifold pressure of 850 lb. per sq. in.). For lighting up a Simplex type sprayer can be substituted in one register of each group, both of which are arranged to accommodate a Lucas removable torch igniter. The high pressure fuel system will be described later in this article.

The high-heat-release type spill-controlled burners are another entirely new development. The atomizers were designed and supplied by Lucas, the burner registers were developed by the Admiralty Fuel Experimental Station, Haslar, with modifications by Babcock & Wilcox.

DESIGNED PERFORMANCE

The turbines, a port hand set, have been designed to develop a maximum output of 30,000 s.h.p. at about 200 r.p.m. They were designed and manufactured by the English Electric Co. Ltd., Rugby.

The steam pressure at the inlet to the nozzle valve chest for powers up to 20 per cent is 695 lb. per sq. in. falling to 550 lb. per sq. in. at full power. The initial steam temperature is 925 deg. F up to 60 per cent power, being controlled to 825 deg. F above that output. The steam temperature is reduced to 725 deg. F over the whole power range when maneuvering in normal circumstances, but the turbines are capable of being maneuvered for short periods with steam at 925 deg. F.

An astern power of 7,000 s.h.p. at about 120 r.p.m. when supplied with steam at 530 lb. per sq. in. and 825 deg. F is provided for, but here again the astern turbines can be operated with 925 deg. F steam for periods not exceeding two minutes.

The machinery has been designed for a total working life of 40,000 hours with a full power life of 1,000 hours. The greatest attention has been paid to achieving optimum economy between 20 and 40 per cent of full power.

HIGH-PRESSURE TURBINE

A two-cylinder cross-compound arrangement has been adopted, the output from the two cylinders being more or less equal at full power. The H.P. turbine cylinder is a molybdenum vanadium steel casting and the solid gashed rotor is of 3 per cent

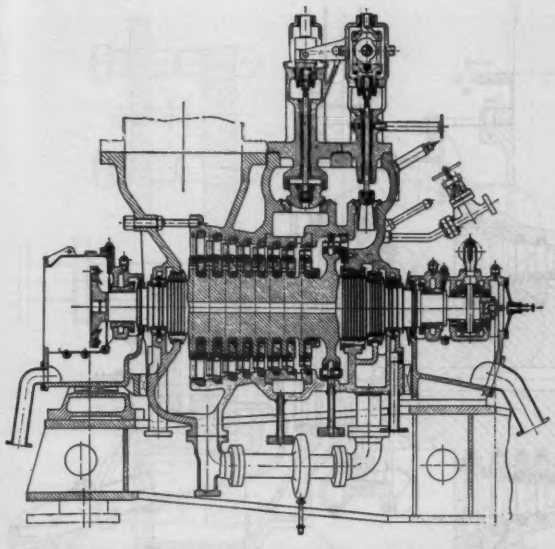

Figure 2. Section through the H.P. turbine showing the rugged construction, cam-operated nozzle group valves, overload valve and windage shield. It is only 4 ft. 10 in. between bearing centers.

chrome-molybdenum steel having one Curtis wheel and eight impulse stages, bladed in H.T. stainless iron throughout. 15,000 s.h.p. is developed by the H.P. turbine at a speed of 7,767 r.p.m.

The turbine is robust and compact (it is only 4 ft. 10 in. between bearing centers) and with the low mechanical and thermal inertia necessary for withstanding the effects of rapid maneuvering. Adequate clearances are provided between the fixed and moving blades, thus minimizing the problem of differential expansion consequent upon thermal transients.

The steam chest is incorporated in the upper H.P. cylinder casting and is surmounted by four cam-operated sequential-opening nozzle group valves. The first three of these valves admit steam to groups of nozzles corresponding to 20, 40 and 60 per cent power. After all these valves are open, further movement of the control handwheel operates a by-pass valve which admits steam to a belt immediately ahead of the third stage. The valve spindles are of packless pattern with leak-offs. All these valves are of spherically-seated venturi type, cam-operated for both opening and closing. The astern control valve is mounted on the L.P. cylinder.

Figure 2 shows that the bearing pedestals are cast independently of the turbine casing and the whole assembly is mounted on a substantial fabricated beam. Generous provision is made for draining the castings. It will be noted that the oil discharge from the rotor thrust pocket is at the top of the housing.

LOW-PRESSURE TURBINE

The all-impulse double-flow L.P. turbine is of double-casing type. It consists of a cast steel cylinder carried within a fabricated mild steel casing. The adoption of double-flow for this comparatively small element (7 ft. 9½ in. between bearing centers) has enabled the blade heights to be halved and rotational speeds to be increased without raising the mechanical stresses. Steam enters through a 1 ft. 10 in. bore transfer pipe and the annulus between the two casings in the cover is closed by a flexible plate. The solid gashed rotor is of 3 per cent chrome-molybdenum alloy and has six impulse stages in each flow. 15,000 s.h.p. is developed at 6,023 r.p.m. The double-flow design has also enabled an astern Curtis wheel to be fitted at each end of the cylinder, thus minimizing rotor and casing distortion. The astern cylinders are of 5 per cent molybdenum alloy, and steam is admitted to an all-round nozzle belt through pipes with sleeve connections in the outer casing. Full astern power (7,000 s.h.p.) is developed at 3,707 r.p.m. Steam deflectors are fitted to prevent the comparatively high temperature astern exhaust from impinging on the last row of ahead blading. Drain gutters are provided immediately forward of the last two fixed rows of L.P. ahead blading.

The moving blades throughout both H.P. and L.P. turbines are of straddle root type. Both casings are lagged with Amosite asbestos.

The turbines are intended for handling by unskilled personnel and the control gear is such that the highest receiver pressure will be maintained without necessity for opening nozzle group valves by hand when increasing speed. The maximum degree of interchangeability has been achieved with respect to components.

PERFORMANCE DETAILS

Power (s.h.p.)	11,500	30,000
Inlet steam press. lb. per sq. in. (abs)	698	565
Inlet steam temp. deg. F.	925	825
Circ. water quantity g.p.m. at 55 deg. F.	27,300	27,200
Vac. in Hg. (Bar 30 in.)	28.7	26.5
Gear efficiency per cent	96.5	97.2
Steam consumption lb. per s.h.p. per hr.	6.27	7.63
Shaft speed r.p.m.	142	200

CONDENSER

The fabricated steel condenser shell is underslung from the lower half of the L.P. casing, there being a 7 ft. 8 in. by 5 ft. 10 in. clear space for steam entry. The cooling water flow is single pass and athwartships. The 70/30 copper-nickel tubes are ⅝ in. o.d. by 19G. and are secured by Crane's Wilkie packing at the inlet end and Crane's fullbox packing at the outlet end. A higher water speed through the tubes than usual (10 ft. per sec.) has enabled the size and weight of the condenser to be kept down. For similar reasons the end covers have been com-

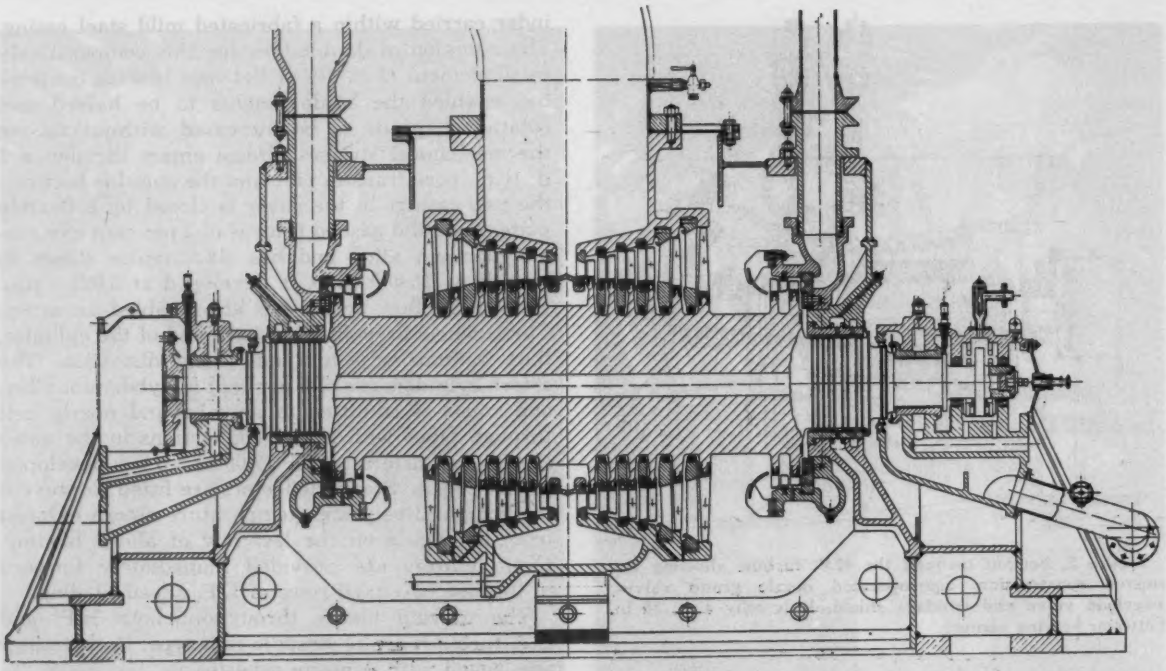

Figure 3. Section through the double-flow L.P. turbine showing the double-casing construction and astern turbines with deflector plates at each end of the rotor.

bined with the water boxes. These are of gunmetal coated on steel on those surfaces in contact with sea water. The condenser has been designed to maintain a vacuum of 26.5 in. Hg. at full power, when supplied with 27,200 gallons of water (55 deg. F) per minute.

GEARING

Vickers-Armstrongs Ltd. have been responsible for the gearing which is of single-helical double-reduction dual-tandem articulated (locked train) type. These are the first large British gears to employ case-hardened and ground teeth for both first and second reductions.

The gear case is supported independently of the turbine at three points. The two side supports are on the transverse line of the main gear wheel and the center line support is at the thrust block. In order to minimize the effect of any malalignment the primary reduction trains are arranged aft of the secondary reduction and are thus within the triangle of support. The L.P. pinion is driven through a Metaduct flexible coupling while a conventional small tooth flexible coupling is used for the H.P. turbine drive. The Metaduct coupling has multi-laminar flexible elements.

The reduction ratios for the H.P. and L.P. trains are approximately 40 to 1 and 30 to 1 respectively. Very high K-factors (over 450 for both first and second reductions) are employed. These compare with a K-factor of about 275 for the hobbed and shaved gears of the Y.100 type of machinery and figures of about 100 previously used in naval gears. It should be understood, however, that the K-factor is not the only criterion of gear performance and many other considerations have to be taken into account.

The gear case has exceptionally clean lines. All oil pipes enter through the lower half of the casing and the cover is cylindrical, affording no foothold. The oil supply is grouped into high, intermediate and low speed bearings and oil sprayers.

Gas carburizing was used for hardening the gear teeth prior to grinding and, at AVGRA, work is being undertaken on the alternative method of tooth-by-tooth induction hardening, which it is hoped will reduce the distortion caused by heat treatment and thus reduce grinding time.

FEED SYSTEM

The closed feed system is a simple one employing a shunt de-aerator and economizer as the only means of feed heating.

The main extraction and de-aerator supply pump is of two-stage centrifugal type by G. & J. Weir, Ltd., driven directly by a vertical spindle turbine, at 1,350 r.p.m. The rating is 412,000 lb. per hr. at 50.5 lb. per sq. in. g. against 28 in. Hg. suction.

A motor-driven Drysdale Wee Mac harbor service de-aerator supply pump is also provided. This has a duty of 24,000 lb. per hr. at 25 lb. per sq. in. g. and 180 deg. F.

The condensate is supplied to the twin main air ejectors as the cooling medium. These are also by

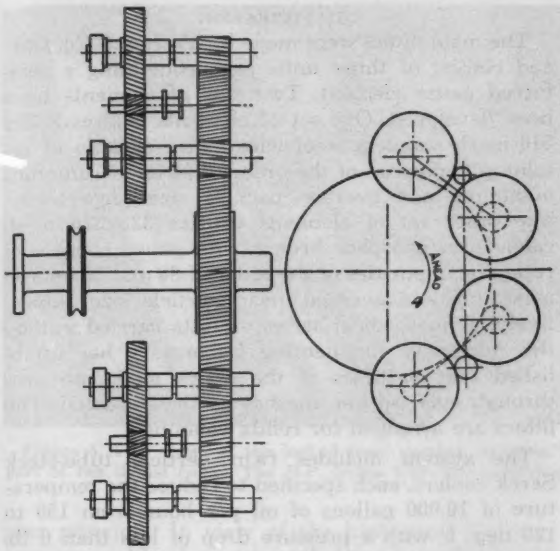

Figure 4. Arrangement of dual tandem reduction gears. It will be noted that the primary trains are aft of the secondaries.

Weir, and of a new two-stage type with vertical tube coolers. They are specified to maintain a vacuum of 28.2 in. Hg. when dealing with 90 lb. of air per hr. with associated vapor and when circulated with 80,000 lb. per hr. of condensate at 98 deg. F. The ejector coolers are each capable of passing up to 412,000 lb. per hr. of condensate with a pressure drop not exceeding 5 lb. per sq. in. After leaving the ejector the condensate is used as the cooling medium in a gland vapor condenser and then enters the shunt de-aerator.

DE-AERATOR

This unit was supplied by Hick, Hargreaves & Co. Ltd., of Bolton, and is of full feed flow, direct-contact float-controlled type. It is supplied with auxiliary closed exhaust steam at 10 lb. per sq. in. g. and 530 deg. F automatically supplemented with reduced steam from the main saturated range to maintain the pressure at 10 lb. per sq. in. g. The de-aerator is designed to heat 346,000 lb. of water per hr. at 165 deg. F and containing up to 0.2 cc. per liter of oxygen to 240 deg. F. The final oxygen content is specified to be less than 0.025 cc. per liter.

The heated feed water is withdrawn from the de-aerator by a motor-driven de-aerator extraction pump. This Weir unit is of double-entry vertical centrifugal type, direct-driven by a 30 h.p. motor at 1,710 r.p.m. 440 volts, 3-phase, 60 cycle, E.D.C. motor. The duty is 460,000 lb. per hr. at 39 lb. per sq. in. g. when supplied with feed at 240 deg. F and 10 lb. per sq. in. g. In the event of failure of any part of the de-aerator system, the main condensate extraction pump discharges through the by-pass direct to the feed pump suction. The next components in the feed circuit sequence are the main and auxiliary feed pumps.

TURBO FEED PUMPS

These feed pumps are of Weir four-stage vertical centrifugal type, driven by geared turbines. The pumps have cast steel barrels with internal gunmetal ring sections. The impellers for the first two stages are opposed to those of the last two stages in order to balance the pump hydraulically. A single impulse turbine having one pressure and two velocity stages within a casing formed half by the fabricated frame and half by the detachable cast steel housing is mounted at the top of the unit. The turbine wheel and pinion is forged integrally with the Ni-Cr-Mo shaft and the blading is of stainless iron. Creep-resisting steel is used for the nozzle box and segments. The turbine shaft runs in white metal-lined journal bearings and the gland packing is of labyrinth type. The turbine drives the pump through single helical reduction gearing. The gear wheel shaft also runs in plain journal bearings and is solidly coupled to the pump shaft. Michell thrust bearings are fitted to both primary and secondary shafts and the gearing is contained within a fabricated case. These pumps have their own integral lubrication system incorporating a gear-type oil pump, Serck oil cooler strainer, pressure gauge and hand-operated priming pump.

The pump is controlled by a differential pressure governor which opens the turbine nozzle groups in sequence to give a rising characteristic. The pump discharge is a venturi tube with pipes leading to the pressure governor and the characteristic of the pump is such as to follow the feed discharge system resistance line and thus obtain maximum economy of steam at low output. The specified normal duty is 320,000 lb. per hour against 840 lb. per sq. in. gauge when supplied with water at 32 lb. per sq. in. and 240 deg. F. The turbine runs at 10,000 r.p.m. (4,375 r.p.m. at the pump) taking steam at 550/700 lb. per sq. in. and 825/950 deg. F from the auxiliary range and exhausts against a back pressure of 20 lb. per sq. in. The overload rating is 384,000 lb. per hr. On leaving the feed pump the feed is taken through the main feed checks to the economizer. There is thus no feed heater of the generally accepted type.

LUBRICATING OIL SYSTEM

An orthodox lubricating oil system, incorporating drowned suction pumps, coolers and filters, is adopted. A battery of Tecalemeters has been provided at Pametrada to measure the actual quantities being delivered to each point.

Forced lubrication pumps of both turbine and motor-driven type are provided. The requirements for the forced lubrication pumps were for minimum weight combined with reliability and ease of maintenance. These aims have been met by a high-

speed Drysdale design of the utmost simplicity. Reduced weight coupled with improved reliability and ease of upkeep have resulted. The higher speed has led to smaller and lighter components and to an added saving in weight and space required for spare gear. The need to reduce the size of the oil drain tank and consequently the volume of system oil carried has added considerably to the severity of the demands on the pump. The total oil in the circuit is equivalent to approximately one and a half minutes' supply.

DROWNED-SUCTION PUMPS

The immersed tank type of pump was chosen because this avoids the necessity for priming; also the absence of suction lift dispenses with expansion of the air which is inevitably entrained in the oil. Other advantages gained by this arrangement are that all suction pipes and valves are eliminated and space is saved. The stuffing box is only called upon to retain a pressure of about 1/10 lb./sq. in. of oil but, in the event of a flooded engine room, is required to exclude sea water from the tank under a head of 15 feet.

A centrifugal rather than a piston displacement design was used because it reduces the components to the desirable minimum of one shaft, one impeller, one volute, two journal and one thrust bearings. The centrifugal pump is relatively independent of fine running clearances and is capable of delivering an increasing volume of oil with reduced resistance to the flow consequent upon wear in the main machinery.

The choice of speed was limited because one pump was to be motor-driven from the 60-cycle system. The choice of 3,600 r.p.m. was taken since this speed enabled the output to be achieved in a single stage and considerably reduced the disc friction of the viscous oil. An efficiency in excess of 60 per cent for oils with a viscosity of up to 140 seconds Redwood No. 1 has been obtained, a figure unusually high for such a small unit. Other special features of the design are a means of preventing possible air locking and emergency control arrangements which bring the stand-by pump into operation automatically within a few seconds of a fall in oil pressure. The shaft is located by a double purpose ball bearing and runs in two Glacier journal bushes. The turbine-driven pump is directly driven by a Weir turbine through Silentbloc link-type couplings. The turbine takes steam at 550 lb./sq. in. and 825 deg. F and exhausts against a back pressure of 20 lb./sq. in. The specified duty is 20,000 gallons per hour against 50 lb. per sq. in. gauge, with oils having a viscosity of between 134 and 81 seconds Redwood No. 1. Maximum power is required when starting up from cold when the viscosity may be down to 4,500 seconds Redwood No. 1. This is achieved by opening auxiliary nozzles.

OIL FILTRATION

The main filters were made by Yarrow & Co. Ltd., and consist of three units each containing a reinforced gauze element. Two sets of elements have been developed. One set of elements utilizes 2/76x 510 mesh stainless steel wire gauze capable of retaining impurities of the order of 94 and 37 microns maximum and average particle size respectively. The other set of elements utilizes 325x325 mesh calendered phosphor bronze wire gauze capable of retaining impurities of the order of 80 and 30 micron maximum and average mean particle size respectively. A methodical series of tests carried out by the Admiralty Engineering Laboratory has established that particles of the above sizes can pass through even so fine meshes as these quoted. The filters are arranged for reflux cleaning.

The system includes twin vertical tube-stack Serck coolers, each specified to reduce the temperature of 10,000 gallons of oil per hour from 150 to 120 deg. F with a pressure drop of less than 6 lb. per sq. in. across the oil side.

Automatic temperature control equipment comprises a temperature-sensitive element in the oil outlet from the H.P. pinion bearing which has the highest rubbing speed, which monitors a British Arca compressed air-operated valve which controls the flow of sea water through the main lubricating oil coolers. Another method of temperature control which has been adopted is the use of a thermocouple embedded in the white metal of one of the highspeed gearing bearings. The signal from the thermocouple is transmitted to a single point electronic indicator, developed by Messrs. Cambridge Instrument Co. Ltd., which in turn monitors the above noted British Arca compressed air-operated sea water control valve. A third method employs a continuous reading viscometer developed by Elliott Bros. to which is applied the oil leaving a high speed gearing bearing, its temperature being controlled to maintain a constant viscosity. Numerous thermocouples are embedded in the bearing surfaces for temperature indication. The method of recording is referred to elsewhere in this issue in connection with equipment fitted in H.M.S. *Hardy*.

HIGH THROUGHPUT CENTRIFUGING

An interesting new technique is the use of centrifugal separators at high throughput. A standard 200 gal./hr. Alfa-Laval Centrifugal separator is fitted with a separately-driven supply pump capable of supplying the separator at a throughput greatly in excess of the manufacturer's nominal rating. It has been found that the higher throughputs can be handled without a significant increase in the maximum and average size of solid particles extracted or in the solid and liquid extraction efficiencies. The quantity of solid and liquid impurities extracted per unit time is, therefore, of course, much higher. The unit operates on the normal by-

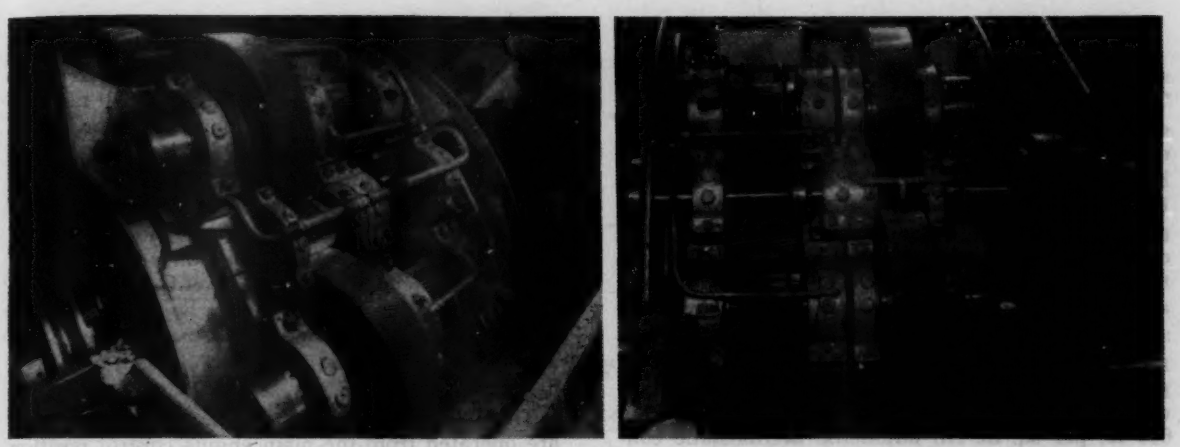

Figure 5. Two views of the locked train gearing showing, left: the L.P. trains with vernier couplings in the foreground and part of the thrust collar. The H.P. trains with the turning gear are seen on the right.

pass principle. In view of the high gear performance, special load carrying oils have been developed and may be used.

CIRCULATING WATER AND DYNAMOMETER

Circulation water for the main condenser is obtained from the Pametrada main circulating system which is supplied by a Sulzer pump mounted on a jetty projecting into the Tyne. An additional booster pump and recirculation system are fitted, the latter to enable high inlet water temperatures corresponding to tropical conditions to be obtained. Flexibility in the main circulating system is achieved by Neoprene/Nylon expansion bellows pieces made by the Andre Rubber Co. Ltd., in conjunction with Yarrow & Co. Ltd. These permit 4 in. relative movement of adjacent flanges in any direction.

Power is absorbed in a large Vulcan Deschimag hydraulic dynamometer which was obtained after the war from the A.G. Weser, Bremen. After refitting and providing means of lubricating the guide vane spindles this has proved sensitive and easy to control.

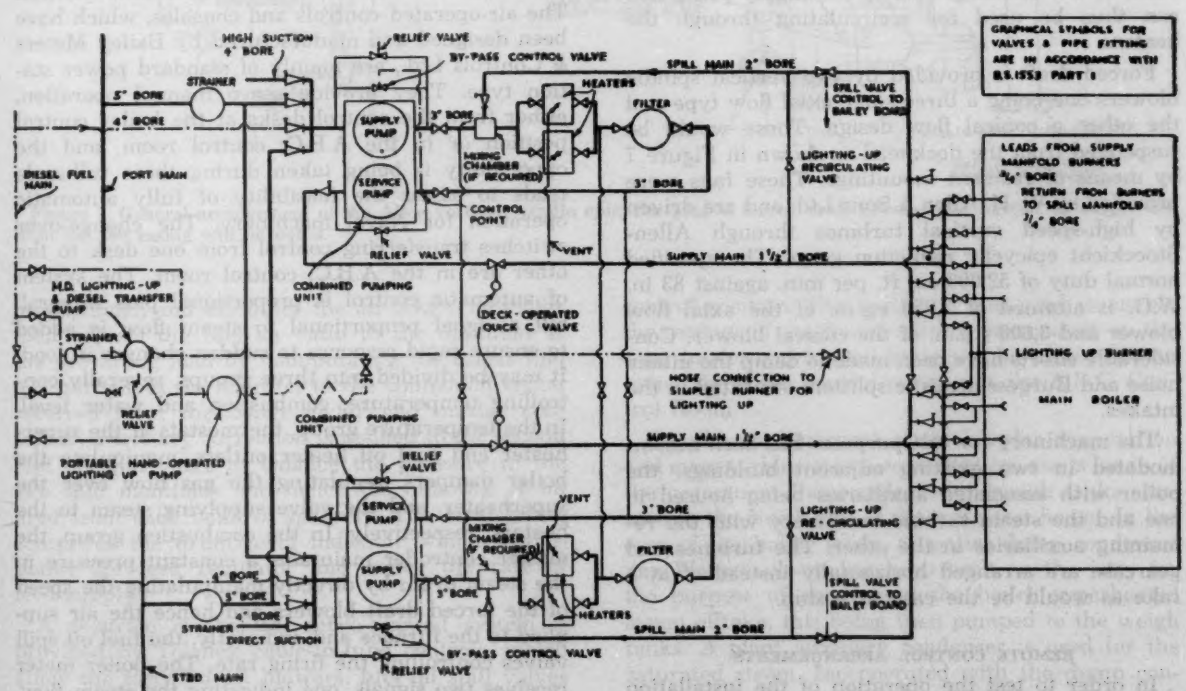

Figure 6. Schematic diagram of oil fuel system showing duplex pumping units and spill arrangements.

FUEL PUMPS, HEATERS AND FANS

The use of spill-type burners has called for a fuel system employing two pumps operating in series. This arrangement can be best described with reference to Figure 6. It will be seen that a supply pump operates in series with a service pump, the former having approximately 15% greater capacity than the latter, the surplus being returned to the supply pump suction. Both are of Mirrlees' Imo rotary-displacement type, driven by a single Weir turbine through reduction gearing. Twin Serck oil heaters are arranged in parallel, each being of the vertical secondary-surface single-pass type with three tubes per unit. Each heater is designed to raise the temperature of 7,500 lb. of oil per hr. from 60 to 230 deg. F when supplied with saturated steam at 600 lb. per sq. in. An automatic thermostatic control is fitted to each pair of heaters to regulate the oil outlet temperature to any desired temperature between 150 deg. F and 230 deg. F. The viscosity of the oil on entry may be as high as 7,500 seconds Redwood No. 1, with an oil pressure of not more than 100 lb. per sq. in. After leaving the heaters the oil passes through a filter and the high-pressure service pump, whence it is led to the manifold on the boiler front. Numerous cross connections would be provided as shown in Figure 6, which illustrates the system as it would be installed on a sea-going ship. The burners have a very wide turn-down range and normally all are lit. Output is controlled by valves in the spill main either manually or automatically from a Bailey board. The spill main returns to the discharge side of the supply pump and can thus be used for recirculating through the heaters.

Forced draft is provided by two vertical spindle blowers one being a three-stage axial flow type and the other a conical flow design. These would be suspended from the deckhead as shown in Figure 7 by means of resilient mountings. These fans were provided by W. H. Allen & Sons Ltd. and are driven by high-speed vertical turbines through Allen-Stoeckicht epicyclic reduction gears. The specified normal duty of 52,000 cu. ft. per min. against 83 in. W.G. is attained at 2,850 r.p.m. of the axial flow blower and 3,600 r.p.m. of the conical blower. Considerable efforts have been made to damp the intake noise and Burgess acoustic splitters are fitted in the intakes.

The machinery for test purposes has been accommodated in two existing adjacent buildings, the boiler with associated auxiliaries being housed in one and the steam turbine machinery with the remaining auxiliaries in the other. The turbines and gearcase are arranged horizontally instead of at a rake as would be the case in a ship.

REMOTE CONTROL ARRANGEMENTS

In order to test the operation of the installation by remote control, a special room has been erected in the test house corresponding to the Atomic, Bacteriological and Chemical warfare remote control room on board ship. From this room it is intended that it will be possible for a small number of personnel to control the whole installation.

During normal steaming, the machinery, which is basically arranged to operate satisfactorily when the watchkeepers have withdrawn to the A.B.C. control room, is controlled from two positions, the main engine control position and the boiler control position. It is intended that, under A.B.C. conditions, the whole of the machinery may be brought under remote control from the A.B.C. control room for a considerable period once the boiler has been flashed.

The ahead and astern turbine maneuvering valves are operated from the main engine control position by Chadburns torsion rods and gearing and this control is duplicated in the A.B.C. control room.

To allow the fuel oil supply to be shut off in an emergency two master valves are fitted, one in each system, which may be operated by a Bloctube push/pull rod control, either from the boiler control position or outside the boiler house. The main stop valve mentioned above, under Chadburns rod gearing, can also be servo operated by means of a Lockhead hydraulic system from the boiler control position, engine control position and A.B.C. control room.

AUTOMATIC COMBUSTION

The operation of the boiler is arranged for either manual, servo manual or fully automatic control. The air-operated controls and consoles, which have been designed and manufactured by Bailey Meters & Controls Ltd., are mainly of standard power station type. They provide servo manual operation, either from the control desks at the boiler control position or in the A.B.C. control room, and the opportunity is being taken during these full-scale trials to assess the feasibility of fully automatic operation for Naval machinery. The change-over switches transferring control from one desk to the other are in the A.B.C. control room. The system of automatic control is proportional plus integral, but a signal proportional to steam flow is added to ensure rapid response to sudden changes in load. It may be divided into three groups, severally controlling temperature, combustion and water level. In the temperature group, thermostats at the superheater and fuel oil heater outlets, manipulate the boiler dampers, regulating the gas flow over the superheater, and the valve supplying steam to the heaters, respectively. In the combustion group, the master controller maintains a constant pressure in the steam drum by directly manipulating the speed of the forced draft blowers and hence the air supplied to the furnace and, indirectly, the fuel oil spill valves controlling the firing rate. The boiler meter receives two signals, one indicating the steam flow, to which the fuel flow is assumed to be directly

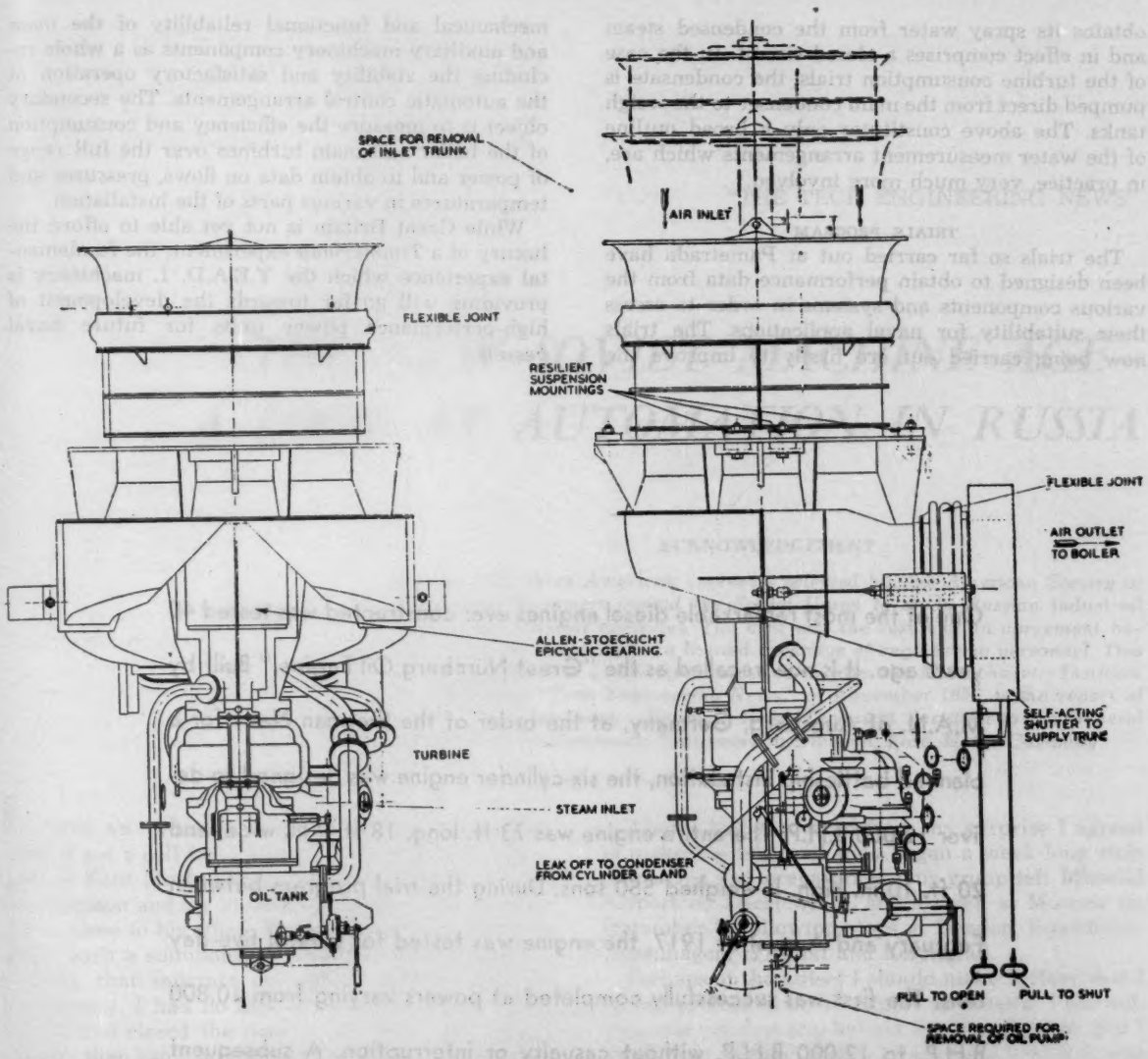

Figure 7. General arrangement of the Allen vertical-spindle epicyclic-geared forced draft blower. The method of suspension from the fan casing will be noted.

proportional, and the other the air flow. The meter then adjusts the fuel/air ratio to the optimum at the prevailing load by manipulating the Lucas fuel oil spill valves. In addition to the compound signal received from the boiler meter and master controller, a tertiary correction is applied to the second fuel oil spill valve to balance the pressure in the two spill manifolds and hence the quantity of oil fired from each bank of sprayers. The level group comprises the drum level indicator which manipulates the feed regulator and hence the rate of feed supply.

A separate mechanical servo-manual system is provided by Teleflex cable-in-tube controls, which allow the forced draft blowers, fuel oil spill valves and fuel oil heaters to be adjusted from the boiler control position. This system is also used to enable the settings of the Bailey system thermostats on the superheater and fuel oil heaters to be adjusted from either the boiler control position or the A.B.C. Control Room.

For the measurement of total boiler evaporation and main turbine steam consumption, use is made of the permanent Pametrada 20-ton weigh tanks situated at the North end of the main test house. In the case of the boiler trials, a special dump condenser (ex Weapon-class) has been built on the jetty for the purpose of condensing the boiler superheated steam offtake, this being then pumped to the weigh tanks. A plant auxiliary condenser is used for the saturated steam. Incorporated with the dump condenser is an essential desuperheating system which

obtains its spray water from the condensed steam and in effect comprises a closed circuit. In the case of the turbine consumption trials, the condensate is pumped direct from the main condenser to the weigh tanks. The above constitutes only a broad outline of the water measurement arrangements which are, in practice, very much more involved.

TRIALS PROGRAM

The trials so far carried out at Pametrada have been designed to obtain performance data from the various components and systems in order to assess their suitability for naval applications. The trials now being carried out are firstly to improve the mechanical and functional reliability of the main and auxiliary machinery components as a whole including the stability and satisfactory operation of the automatic control arrangements. The secondary object is to measure the efficiency and consumption of the boiler and main turbines over the full range of power and to obtain data on flows, pressures and temperatures in various parts of the installation.

While Great Britain is not yet able to afford the luxury of a *Timmerman* experiment, the fundamental experience which the Y.E.A.D. 1. machinery is providing will go far towards the development of high-performance power units for future naval vessels.

One of the most remarkable diesel engines ever constructed was tested 40 years ago. It is now recalled as the "Great Nürnberg Oil Engine." Built by M.A.N. of Augsberg, Germany, at the order of the German Navy for a planned battleship installation, the six-cylinder engine was designed to deliver 12,000 B.H.P. The entire engine was 73 ft. long, 18 ft. 9 in. wide, and 20 ft. 10 in. high. It weighed 550 tons. During the trial program between February and August of 1917, the engine was tested for several five-day runs. The first was successfully completed at powers varying from 10,800 B.H.P. to 12,000 B.H.P. without casualty or interruption. A subsequent five-day trial proved its ability to operate on anthracite tar oil with paraffin as an ignition primer, with a fuel consumption of 0.477 lb. per B.H.P.-hr. Later overload tests were carried out at powers up to 16,000 B.H.P. The engine was scheduled for installation in the German battleship "Prinzregent Luitpold," but was ordered destroyed by the Armistice Control Commission.

"THE TECH ENGINEERING NEWS"

THE NEW SOVIET MACHINE AGE— A LOOK AT AUTOMATION IN RUSSIA

ACKNOWLEDGEMENT

Late in 1955, three American engineers selected by The American Society of Mechanical Engineers visited the Soviet Union to study Russian industrial plants and technical institutes. The visit was the result of an agreement between the two countries for a limited exchange of engineering personnel. This article, reprinted in a slightly abridged form from the Massachusetts Institute of Technology "Tech Engineering News," of November 1956, is the report of one of these three men.—Nevin L. Bean, Technical Assistant to the General Manager of the Automatic Transmission Division, Ford Motor Company.

IT WAS AN ordinary morning in late November when I got a call from Marvin Katke, general manager of Ford Motor Company's automatic transmission division and my immediate superior. He wanted me to come to his office. There was nothing unusual about such a summons, so I walked the few feet of hallway that separate our offices with no loss of equanimity. I had no hint of what he had in mind until I had closed the door to his office and seated myself; then came a proposal for which I was totally unprepared.

"Nevin," he said, "we'd like for you to go to Russia. You'll have about a week to get ready."

Nothing he could have said would have surprised me more.

Then Mr. Katke went on to explain that our government and Russian officials had worked out an agreement for an exchange of technical personnel to observe industrial and engineering processes. The Russians had already sent their engineers to this country to look at machine tools and visit industrial plants. Now three American Engineers were to make a reciprocal trip to the Soviet Union to visit Russian industrial plants and technical institutes. I had been chosen as one of the three. My colleagues on the trip were to be Dr. Weldon Brandt, engineering manager of director systems for Westinghouse Electric Company of Pittsburgh; and Dr. A. C. Hall, general manager of the research division of Bendix Aviation Corporation at Detroit.

When I had recovered from my surprise I agreed to make the trip, and then began a week-long rush of briefing and preparation. Our group left Idlewild Airport on December 4, and arrived at Moscow on December 7, following stops at London, Stockholm, Copenhagen, Helsinki and Leningrad.

Perhaps at the outset I should make it clear that I do not profess to be an expert on Russia; I am not. This was my first trip behind the Iron Curtain and I spent only 16 days there. In so short a time it was impossible for me to learn of all the forces which motivate such a nation.

I should also like to disclaim any qualification as a political pundit. I am an engineer; I went to Russia to examine the quality and the state of the science of engineering in Russian industry. I confined myself strictly to that field of inquiry, avoiding all discussions of a political nature. If there are political connotations in what I saw and what I report on, then I leave it to those skilled in politics to assess and evaluate those connotations.

In summary form, we found that on the whole, the Russian plants we saw are not as productive as those in this country. They are not as well organized, not as clean and not as well lighted. Most material handling systems are obsolete. Much of the machinery is old, but most of it is in good condition and is being used to good advantage. However, we found that many of the adverse conditions we saw are in the process of being changed very rapidly. New

automatic production machines are being designed and built, and the engineering on some of these lines would be a credit to any engineering group anywhere. Over all, the interest in automation appeared to be greater in Russia that it is in the United States. The Russians are no longer building manual production machines if automated lines can be made. If plans we saw are carried out, Russian factories will have the machinery and techniques to make giant production strides within the next five years. Within ten years many of their production facilities will be comparable to ours, and within 15 years their production facilities and techniques may be superior to ours unless a new emphasis is placed on automated production designing in this country.

I should like to make it very clear that I am speaking only in terms of advances in machine tools, production techniques and engineering know-how. The Russians show a high quality potential in these fields. However, it must be remembered that national production is dependent upon factors other than tools, techniques and engineering know-how. It is also dependent upon the supply of such basics as steel, coal, electric power, productive labor, and a good transportation system. I am not qualified to speak from first-hand knowledge of the supply of these basic industrial ingredients. I was not shown their plans for coal, steel or power production, nor was I given any blueprint of their plans for transportation system improvements. However, since returning from my trip I have seen an article from the *London Times* of February 3 which touches on these basics. It might help to round out the picture if I quote briefly from that article which began this way:

> The sixth Five-Year Plan, covering the years 1956-60, is an important landmark in Soviet affairs. It comes at the close of a quarter of a century of planned economy, during which the Soviet Union was engaged in an industrial race with the nations of Western Europe. This race is now essentially concluded; and Russia has won it, at least in basic industry and engineering.
>
> Last year Russia produced 390-million tons of coal, against 330 million tons mined in Great Britain and Western Germany; 45-million tons of steel against a combined British and German output of 41-million tons; and 166-billion kilowatt hours of electricity, compared with the joint British-German output of 155-billion kilowatt hours . . .
>
> With the launching of the present plan a new contest is opened. The Soviet Union now aspires to 'catch up with' the United States . . .

I cannot personally vouch for the assertions and opinions reported by the *London Times*. However, that newspaper has a wide reputation for careful evaluation and factual reporting, and I include its appraisals in this report as collateral material.

Perhaps the most important key to future Russian advances in automation lies in an organization called "ENIMS" in Moscow. This organization is the Experimental Scientific Research Institute for Metal Cutting Machine Tools. We had an opportunity to tour this institute and talk with the director, Mr. Vladzlyevski, and with members of his technical staff who are responsible for various phases of tool design and construction.

The ENIMS organization, under supervision of the Ministry of Machine Tool Building and Instrumentation, carries on research and development projects exclusively for the machine tool industry. It controls design and production of all machine tools constructed in the Soviet Union. Other factories may design tools, but those designs must have ENIMS approval before adoption for production. ENIMS is generally concerned with development of equipment of the future—four to five years hence—leaving to other factories the construction of machines which are up-to-date by present day standards. In its efforts to apply improvements to the machine tool industry, ENIMS may veto the construction and installation of new units that do not incorporate latest improvements, including automation.

The organization is divided into three major departments—technology, metallurgy and design. It is further subdivided into some 50 laboratories and technical divisions, with each type of machine having its own laboratory. Electric and hydraulic laboratories serve the other laboratories on a consulting basis.

The plant has a technical library of more than 200,000 volumes, plus a special department that screens, analyzes and interprets technical press articles from other countries. Processes considered of sufficient interest are described in one of the two ENIMS publications which are distributed throughout industry.

In general, industrial programs are planned on a five-year basis. ENIMS co-ordinates this planning, which includes the scheduling of installation of production machinery in factories. Therefore, ENIMS is able to control the types of machines built, the uses to which they are put, and their distribution among various industrial plants.

Beyond the five-year plans, there are 10-year and 15-year plans, but these are rather sketchy. However, ENIMS controls their general direction. Tools are planned at least four to five years ahead, and in drawing up such plans ENIMS uses its own engineering staff, but may also draw on the experience of engineers in industries concerned, as well as from material in the foreign and domestic technical press.

Looking to its 10-year and 15-year plans, ENIMS expects to replace manual production machinery with automated lines throughout Russian industry, wherever possible.

The ENIMS plant employs about 475 engineers who receive from about 1,400 to 3,000 rubles per month in salary. (At official exchange the ruble is worth 25 cents. However, its purchasing power is equivalent to only about 10 cents.) We were told some of these engineers receive up to 2,000 rubles per month as bonuses or royalties.

All engineers hired at ENIMS must have at least three years of factory experience, in addition to their engineering degrees. They work on a wage-plus-bonus plan with very attractive incentives. Many have patents from which they collect royalties paid on the

basis of a percentage of profit for the state resulting from an invention. A royalty may be collected as long as a patented invention is used, and in some cases royalties may exceed basic wage rates of the engineers. Copies of patents we saw had serial numbers which indicate that about 2,000 patents were granted each year between 1951 and 1954.

The plant is involved in several phases of operation—time testing, vibro static, hardness, rigidity and the general factors of design.

On our tour we saw some very interesting electronic and mechanical applications of automation. We also saw many tracer-type lathes—both vertical and horizontal—and boring mills of various sizes.

A gear grinding machine that attracted our attention was similar to a Gleason, with the exception of the grinding head rotation as synchronized with the gear. They were grinding a small bevel gear. The grinding wheel head reciprocated as it rotated at an angle to the axis of the gear. The head moved back and forth at about 100 strokes a minute as the head rotated to cover a tooth face for approximately 90 degrees. When one face of the tooth was completed, the head returned rapidly to the initial position where it repeated the operation. This machine went through its cycle very smoothly and presented a very formidable appearance.

We were told that they are making every attempt in the factories that design grinding machines to use roller bearing or ball bearing ways. In the case of ball bearings, the ways appeared very similar to ours, except that the V's occurred in both the slide and the way. They advised us that the ball bearing way is used, whenever the weight of the head is not too great, to insure successful operation.

They were designing and building hydraulic contour mills somewhat similar to our Cincinnati Hydrotels. These machines performed a two-dimensional follower operation. The followers actuated directly the valves which controlled the cylinder tables. They claimed extreme accuracy for this machine to what would be comparable to .005. However, I would want to check the dimensions personally before I would concur that dimensions of this tolerance could be held with this type of follower. The general design of the machine appeared to be quite good and they stated that the speed range of the bed would be about 40 millimeters to about 2 meters per minute.

Of unique design, and possibly the most appealing machine that we saw at this plant, was an automatic balancing machine used for controlling the dynamic and static balance on an electric motor armature. Although the machine is designed to accommodate various sizes of work, we saw it operating on a rotor that was between five and six inches on the largest diameter and approximately 12 to 14 inches long. The rotors entered the machine automatically, were picked up and spun automatically; the machine indicated the amount and area of unbalance; a memory device or a registering unit recorded the unbalance and the position of same; the rotor was released; it rolled into another station where it was immediately picked up and metal was removed from the proper location and to the proper amount. Drills approaching both sides of the rotor were used to correct the material unbalance. This machine is designed to such a degree of efficiency that a recheck of the operation performed seemed completely unnecessary.

Another machine that would ordinarily attract attention in a tour such as we made was an electric erosion unit. They had two of these units at this plant and they were generator operated. In the one that was operating, they lowered the electrode to within about a millimeter of the workpiece where it was held in this position automatically as it followed the contour of the work. The electrode was submerged in kerosene. We were told the current used on the particular operation was 10 to 15 amperes and the frequency was about 3,000 pulses per minute in order to cut material approximately one millimeter deep. They seemed quite pleased with the results they had obtained because they proudly submitted several samples of their work claiming extreme accuracy and finish.

In addition to the ENIMS research and development organization, we visited two plants where machine tools are made. One, Ordzhonikidze Plant, was about 25 years old, and the other, known as the Krasny Proletariat, has been in operation for about 100 years.

Ordzhonikidze specializes in making boring equipment. Most of the manufacturing equipment bore foreign nameplates and was of rather ancient vintage, but some of the operations looked quite good. We saw many American machine tools such as Gardner grinders, different types of Cincinnati machines, King vertical lathes, Gray planers and many other familiar types—some rather new. Mr. Kosichev, the plant director, explained that the newer machines were put in as a result of an exchange of materials, and not because of a lack of Soviet supply. He insisted that the Soviet Union is now in a position to supply any and all types of machine tools, precision or standard, as required.

Machine maintenance here was very good, keeping old machines running and in good condition. However, plant facilities in general did not come up to our standards. They were substandard in lighting, layout and material handling facilities. There was considerable crowding in assembly areas.

The technical staff at this plant treated us with exceptional hospitality and appeared to be willing to answer all our questions. Members informed us that when World War II came in 1941, the plant was moved from Moscow to a location behind the Ural Mountains, and then put into operation within 30 days. There it produced war equipment. In 1945 plant equipment was returned to the original Moscow site. We asked Mr. Kosichev how he had become director of the plant. He explained that he came of peasant parentage and had become a designer. Later he became an engineer, then plant technical director,

chief engineer, and finally director, which post he has held for nearly 10 years. He explained that this plant was constructed during the first five-year plan under Stalin's program to build machine tools, and began operation in 1932 using mostly foreign machine tools.

Both the director and his staff stressed the importance of automation from the standpoint of the good of the worker. Almost all of the directors we encountered in Russia harped on this theme, but what we saw in the factories did not indicate there is quite as much concern with worker fatigue and working conditions as the directors would have had us believe.

The plant covered an area of about 270,000 square feet, and has a staff of 3,500 persons, including 450 engineers, some 300 of whom are university graduates. We noted that some 40- to 50-per cent of the workers were women.

This particular plant specializes in cam follower machines; six- and eight-inch horizontal boring mills (comparable to our Giddings and Lewis) with elevating platform type head and an upright column which is about 16 feet high and with a table about 26 feet long; planers of all types similar to our Gray planers; and machines similar to our Cone automatics, as well as special transfer machines.

A horizontal boring mill was of special interest. It had about a nine-foot vertical travel and possibly a 10- to 12-foot horizontal table travel. We were told that they were building three of these per month and that each unit sold for 440,000 rubles. The boring mills seemed to be well designed and very rugged. The vertical tracer lathes that are manufactured here were similar to a single-spindle Bullard, with hydraulic-controlled tracer attachments. We were informed that they could build about 30 of this type of machine each month and that the plant has a capacity of approximately 1,000 machines per year of large and small types. The automatic machines they are making have a capacity of about 450 millimeters.

During our observation, we noticed that the castings used for the machine tools are of excellent quality. However, we were advised that the foundries are in a different location. We also noticed the use of ceramic tools on their turning operations. We were advised that they are cutting steel of a 40 C-scale Rockwell hardness at 800 to 1,000 feet per minute with the ceramic-tipped cutting tools.

The Krasny Proletariat makes turret lathes, vertical spindle machines, six-spindle semi-automatic lathes, camshaft and crankshaft machines, and several types of boring equipment. There we saw our first Russian conveyorized assembly line for machine tool construction. The line is used for assembly of turret lathes.

In this plant also I saw several types of American machines, such as Niles, Carletons and Kings. These American machines were scattered quite profusely throughout the entire plant.

The plant is very well equipped and layout is good, except for a certain amount of crowding. Lighting was poor, however, and material handling facilities were not up to par.

The plant covers nearly 600,000 square feet, with 10,000 to 12,000 square feet devoted to laboratories. It employs from 4,000 to 5,000 workers.

The machine tool produced in the greatest quantity at this plant is a semi-automatic screw machine, or turret lathe, similar to our Warner-Swasey. However, the general streamlining and appearance of the machine has been improved to some extent. I noticed that the clutch teeth, splines, gears and all wearing parts are hardened, mostly by the induction process. We saw an induction hardening machine which is very universal and is of a 200,000 volt capacity. I noted that they even hardened the castellations of round nuts.

One of the most interesting things that I noticed was the production method for assembling turret lathes. They have a floor-type, walking beam conveyor which advances each machine one station per index. I tried to establish the speed of the line, and was informed by the Director, Mr. G. A. Surchev, that it was capable of producing 54 machines per day.

We were taken into another part of their experimental laboratory where we observed a new machine that is being tooled for production. This is a push-button, electronic sizing machine. Push-buttons on panels are used to establish diametrical and lateral dimensions. We were advised that they are providing new machine tools that will replace about 60 per cent of the present equipment in the production of this newly designed push-button lathe.

At the Institute of Automechanics and Telemechanics we saw some very interesting work on the theories of automation. This institute comes under the Academy of Sciences and is under the direction of V. M. Trapeznikov.

Explorations and inquiries at this institute follow three main lines.

1. general theoretical problems
2. theory of automatic controls
3. theory and general structure of telemechanics.

Very exact precision is the goal at the institute. They develop linear controls and impulse systems. Both theory and practice are involved, and they specialize in electronic analogues. They develop and manufacture digital systems, relay actions, and new means for production of measuring machines. They develop hydraulic and pneumatic, as well as electric, controls. They also develop automation for industrial processes, which they were able to tell us about, but not to show us at that time.

They are involved in industrial supervisory controls which they refer to in two manners: (1) the theory of signals supervising systems, and (2) the structure of systems of relay actions for error-detecting methods by impulse under conditions of simultaneous use.

A major portion of the institute's effort is directed towards the basic theory of automatic controls, dis-

crete signal systems, hydraulic and pneumatic systems and contactless control systems. They are very much involved in automation pertaining strictly to industrial processes and emphasize to some degree signal generation, the use of toroidal coils and various modulation systems. In one of the laboratories they exhibited an eight-channel telemetering system which had a frequency modulation scheme with timed distribution of the channels.

One very interesting item they displayed was a unit for pneumatic and hydraulic systems which they called a flapper valve. They stated that they were studying the shape of the orifice to improve linearity because they were endeavoring to eliminate oscillation. The particular unit that we saw in operation was an air orifice that was controlled with levers and weights. They seemed to be especially concerned with the balance of the lever that carried the cone which entered the orifice. We noted that a peculiarity existed because when the cone approached the orifice, there seemed to be an aero-dynamic attraction which would cause the cone to close the opening, and this theory seemed to them a most important study in the source of oscillation.

We were taken into another part of the plant where they showed us an analogue computer that they had designed and built for the study of control systems. This unit was a combination of potentiometers, plug boards with plug-in function units, amplifiers and polarized relays. They set up problems in this machine which required three or four minutes to formulate and, at the same time, they would rearrange the formulas and approach the problem with a different method and still secure the same results. They told us that they had used this computer in studying the flapper valve systems they were experimenting with for the hydraulic and pneumatic installations. They also explained that they were studying automatic regulation systems, using digital systems in the control problems. They have built many digital servos; however, they are using these mostly in their laboratory efforts.

Another area in which they seemed quite interested was the design and construction of a magnetic amplifier control which used a low horsepower motor. It also used a Tach generator with three stages of amplification, the first stage being electronic and the other stages magnetic. When we appeared somewhat interested in this unit, they explained to us that it was an experimental setup and the most of it was made by hand and with materials available. Our impressions were that the analogue computer was the most outstanding development that we had seen at this institute, and our general conclusion was that they are better versed and more successful in their efforts in hydraulic and pneumatic servo systems than in their electrical control units.

At the Institute of Precision Mechanics and Calculating Technology we saw one of the most impressive achievements of Soviet technology, the BESM computer, a high speed computer used in solving scientific problems.

This computer is a three-address machine with a floating decimal point. The staff estimated that it has a production equivalent of about 12,000 human operators. The machine averages 7,000 to 8,000 arithmetical processes per second, while an experienced worker can do only about 2,000 a day with an ordinary office adding machine. Thus, in a few hours it does calculations an experienced worker would not be able to do in the whole of his lifetime with manual equipment. We were told that in less than 20 hours the machine solved a problem containing 800 equations and calling for 250 million arithmetical processes. It is also capable of translating in several languages.

We saw the machine work out one rather novel problem in short order. Practically everywhere we went in Russia we saw chessboards set up, with supervisory personnel playing chess in spare moments. Often men engaged in a game would make two or three moves, then leave the board set up, and return to the game later after attending to other duties. In this case one of two computer technicians playing chess was stymied over the next move. He wondered what the next move should be, looking four or five moves ahead. So he fed the chess problem into the machine and it quickly indicated the move. We asked Professor Lebedev, the director, who would win a game between a Russian chess champion and the computer. He replied that the man probably would win because he could trick the machine.

Professor Lebedev, who designed and built the machine, gave us a technical description of the machine and its operation. He described it as a three-command divisional machine which takes five double betts and in which each bank address has 11 betts. It controls memory for 2,048 numbers. The three-address (bank) system with one move of the machine will fulfill one operation, such as "a + b = c." The single phase goes into the machine, then you add the "b" number to the arithmetic part of the machine; then, from the arithmetic part, the "c" factor is concluded. Professor Lebedev said that a three-address machine operates twice as fast as a one-address machine.

The machine is about three years old and operates 24 hours a day, with Sundays off. The efficiency of the machine is 72 per cent—testing takes about 20 per cent of the time, and about 8 per cent is allowed for error. It is being used in the Academy of Sciences. It is also used for solving problems of industry and other establishments and has a general centralized usage. It has about 5,000 electronic tubes, and special selective checking establishes the condition of tubes that have been installed. They use a problem with known results and proceed to a certain point; then if the results check, the problems are completed. This unit is about 90 feet long and about 10 feet high, and the tube cabinets are about 4 feet thick. The room enclosing the unit is about 100 feet

long. The engineers working on this unit receive from 1,800 to 2,500 rubles a month and, as an Academician, the Professor receives an additional 5,000 rubles over his regular salary.

A verbatim description of the electronic computer written by Professor Lebedev for *Pravda* is as follow:

The lightning "BESM" Electronic Computer, designed and built by the Institute of Precise Mechanics and Computation Techniques, has been functioning for more than three years now at the USSR Academy of Sciences. The machine averages 7 to 8 thousand arithmetical processes per second, while on an office adding machine an experienced worker can do only 2,000 in a shift. Thus in several hours, it does calculations an experienced worker would not be able to do in the whole of his lifetime. One such machine alone does the work of a huge army of several dozen thousand counting clerks.

Since our electronic computer began to operate, it has solved a multitude of problems in diverse branches of scientific knowledge and engineering, enconomizing, as a result, hundreds of millions of rubles.

Here is a concrete example.

In compiling maps from geodesical surveying data, a set of algebraic equations with a large number of unknown quantities has to be solved. Problems containing 800 equations calling for up to 250,000,000 arithmetical processes are solved by the electronic computer in less than 20 hours.

How does our electronic computer work? Before tackling the solution of any problem, it is necesary, with a knowledge of the physical essentials of the process under investigation, to set the assignment in the shape of algebraic formulae, differential or integral equations, or other mathematical relationships. By applying well-elaborated methods of numerical analysis, one may virtually always reduce the solution of such a task to a definite consecutivity of arithmetical processes. These operations are also carried out by electronic computers. To rapidly effect the entire calculation process, the electronic computer does everything automatically.

To dial the number for any arithmetical process, it must be "stored" somewhere. To this end, the electronic computer possesses a "memory" device, consisting of a number of cells. All these cells are numbered, and to use any number, one must dial the number of the cell in which it is "stored." The numbers selected from the "memory" device are relayed to that part of the computer performing the given arithmetical process. The result obtained is then sent to one of the cells of the "memory" device, where it is "stored" until called for in further calculation.

The solution of the task is reduced to the consecutive performance of a series of "commands," which form the programme of computation and are "stored" in the machine, usually in the self-same "memory" device.

The programme of computation, that is, the combination of "commands," ensuring the given consecutive of arithmetical processes to solve the problem is drawn up by mathematicians beforehand.

Many problems require tens and even hundreds of millions of arithmetical processes to solve. Therefore, on the electronic computer, methods permitting the execution of a large number of arithmetical processes by a comparatively small number of "commands" are used.

Apart from "commands" for arithmetical processes, the electronic machine also provides them for logical processes, by applying which the machine enables us, in particular, to translate from one language into another.

In a translation from one language into another, the "memory" device stores not numbers, but words, listed alphabetically, as in a dictionary. The word to be translated is picked out of corresponding words in the other language of which there may be several. The word-for-word translation thus obtained is edited by the machine, with an eye to the grammar syntax of the language.

Calculations on our machine are carried out with numbers ranging from the order of a thousand millionth fraction to one thousand million. Every number has nine figures of value, giving the required accuracy for most of the problems to be solved. In some cases, as for instance, in the solution of certain astronomical problems, the machine can perform the computations with the value of the figures doubled.

Special electronic radiation tubes, somewhat reminiscent of television tubes, are employed in the machine for the main operative "memory" device. The numbers are "stored" as charges at various points of the tube screen. This "memory" device may contain 1,023 numbers or "commands." The choice of any number and the recording of the result is done in 12-millionths of a second.

To extend the range of problems for solution, in which a large number of figures are called for, the machine has an additional, slower, "memory device," consisting of a magnetic drum and tape.

The computation results are recorded on the tape, and subsequently filmed outside the machine on a photo-printer operating at a speed of 200 numbers per second. Furthermore, there is an electrochemical printer, run directly by the machine with a speed of one and a half numbers per second, used chiefly to print control values, to enable the operator to follow the computation process.

The machine can operate round the clock. It has some 5,000 electronic tubes, the service term of each exceeding 10,000 hours. Tube replacements are done during checking shut-downs. The machine itself is operated by two engineers, and one technician per shift.

Ever since the lightning electronic computer of the USSR Academy of Sciences has been in use, it has shown a high efficiency, winning the appraisal of Soviet and foreign scientists and experts. At a recent international conference on electronic computers at Darmstadt, a number of American and German scientists said our machine was the fastest in Europe and abreast with modern American computing machines.

Soviet scientists are now occupied with devising still better computation units and are looking for more fields for their application. This constitutes a serious factor for technical progress in our country and an important requisite for the successful advancement of the main branches of science.

At the Institute of Standard Measures and Measuring Instruments we saw the equivalent of our U.S. Bureau of Standards. The main institute is located at Leningrad, but we visited a branch institute at Moscow which provides standards for the Moscow area.

The buildings housing the institute were very old, but the equipment within the buildings was exceptionally good, very modern and very complete. We saw interferometric equipment, spectographs, instruments for checking screw threads, and many pieces of optical apparatus which were very modern and appeared to be very efficient. Much of the equipment involving gases and fluids, as well as electrical equipment for carrying out tests up to 100,000 volts, was created in the Soviet Union.

The most complete application of automation on our itinerary was at the Kaganovich Ball Bearing Plant, the top bearing-producing plant in the Soviet Union. This plant produces some 1,300 types of ball and roller bearings ranging in size from 150 grams to four tons. A year's output is approximately 60 million bearings.

This plant had several lines, only one of which was completely automated. On the automated line, which

had been in production only three months, all operations are performed automatically, including the handling between processes, until the packaged bearing is ready for shipping. Hot rolled forgings are dumped into hoppers at the start of manufacture, then the parts proceed into automatic chuckers, through a series of processes—including heat treat, grinding operations, final inspection, assembly and test—and on into a packaging machine where the bearings are wrapped in oil paper and sealed in individual cardboard packages. The only operators on this line are the people who adjust and maintain the production equipment.

Since returning from my trip to Russia I have visited an automated bearing production line in this country. I was unable to watch the Russian line and the American line long enough to determine which is the more efficient, but from an engineering standpoint, the Russian line looked better. The automation applied to that Russian bearing line would be a credit to any engineering or machine building group, and already their technicians have begun construction of another automated line which will have improvements over the one we inspected. Their plans call for approximately 30 automated bearing lines by 1960.

The second Kaganovich bearing line we watched is using standard machines with automatic handling between operations. On this line, loading and unloading had been automated, and it had been done in such a manner that several different types of bearings can be run on this line with minor changes to the setups. This line was a very good example of the adaptation of automation to semi-automatic machines. The Russian engineers had connected machines with automatic material handling lines and conveyors, coupling these with new and improved controllers on the machines themselves. Two such lines are in operation and two more are under construction. They claimed this adaptation had raised productivity 14 to 15 per cent and reduced costs by 8 to 9 per cent.

Of course the Russians are quite proud of improvement factors accomplished during the five-year plan just ended at the Kaganovich plant. Using 1950 as a basis of measurement at 100 per cent, during the following four years and 10 months they increased productivity to 160.3 per cent.

Since more than half the employees at the Kaganovich plant are women, there is a problem of caring for children. The plant takes over this problem by providing kindergartens, summer camps and summer cottages. Medical service is provided for all employees and their families. There are emergency medical stations throughout the factory, plus outpatient clinics which can arrange practically any medical service required. Approximately 100 doctors and 200 nurses serve the 12,000 workers and their families—or about 40,000 persons in all. In each shop, doctors check working conditions with respect to health hazards.

In most cases the larger Russian industrial plants are almost cities within themselves. They furnish and maintain living quarters for the workers, as well as "recreation palaces" which include facilities for all types of sports, theater groups, motion pictures and ballet groups. Many of the plants produce the electrical power necessary for lighting the homes and facilities of the workers. The child care programs for workers at the Kaganovich plant were also found at other Soviet plants.

At our insistence, Ambassador Bohlen and American news correspondents in Moscow were allowed to accompany us on our trip to the Kaganovich Plant. They were not permitted to go with us to any other plants we visited.

The Kaganovich plant lists its grades of manufacture as follows:

Type	Description	Run Out (Microns)
N	Usual Precision	100
P	Superior Precision	80
V	High Precision	60
A	Highest Precision	33
S	Special Precision	20-16-10

We noted especially that the machines used in the one automatic line differed to a great extent from those used in the United States. The main difference in the machine construction was the consideration they give to complete automation. The metering of the product into the machine, the loading and the unloading were all provided as an integral unit. We were amazed at the storage facilities that were provided between operations. These storage units were approximately seven feet square and about nine feet tall and housed up to 4,000 parts. The electric furnaces were placed in the direct lines of automation. We observed about 10 or 12 people scattered about the department who apparently were set-up men. About four or five of these people were stationed at the electronic inspection units near the end of the line as well as at the assembly and packaging units. Our inspection of the automatic line lasted only about 30 minutes.

The wage structure at this plant compared with those of other plants visited. We were surprised that, in many departments where automation has not been applied, the workers produce on a piece-work basis. We were told also that, in many cases, dies and tooling were produced on a piece-work basis and that in cases where scrappage occurred, the worker was obliged to stand a portion of the loss. It was explained that this had a great tendency to encourage efficient and accurate operation.

At the Krasny Zarya factory at Leningrad we saw Russian production facilities for telephones and home and automobile radios. This factory is under the Ministry of the Radio Technical Industry.

The particular plant we visited was organized in 1900, and was damaged to some extent during the war. However, considerable restoration has been effected since 1944. The factory makes telephone exchanges, and instruments for automatic dialing for units which serve 50 to 1,000 subscribers. Larger

units are made up of multiples of the 1,000-unit devices. Annual production of automatic telephone equipment will take care of about 200,000 new subscribers each year.

The Krasny Zarya factory also makes relays for telephones, vibrators, and radio sets. The plant covers about 400,000 square feet and employs about 5,000 workers, of whom some 13 per cent are engineers and technicians. About 60 per cent of the technical workers are college graduates.

We observed that the press shop was doing good work but that most of the operations were hand loaded. We did not see progressive dies, nor did we see automation applied to the loading and unloading of the press. We looked at the dies, and they appeared to be well built and in good condition. The parts being punched gave all indications that the dies were working very satisfactorily. In some cases where automation could have been applied for loading and unloading, supervisors stated that they had to have an operator at the machine regardless, so there was no general profit in applying automation.

They plan on making a smaller exchange this vear that can be used in the collective farming areas. They told us that they are making automatic equipment only, and that no hand equipment was being manufactured at this plant. They make relays for the entire telephone industry and also make vibrator power supplies for automobile radios, including the vibrator, transformer and assembly unit. Although we did not see this portion of the plant, they informed us that they are also making radios for home use.

One interesting operation was that for making springs for relays automatically. They had one machine that did approximately ten operations and then transferred materials to a second machine where parts were automatically mounted with the relay and welded in place. They were quite emphatic in explaining to us that in case of failure in any operation, the machine would automatically stop until the error was corrected.

The average wages are about 800 rubles a month. However, some workers will make as much as 2,000 rubles a month in rewards, bonuses or royalties. The tool makers are paid up to 2,000 rubles per month, and the engineers average from 1,100 to 2,500 rubles a month. They also told us that the Director is paid a 40 per cent bonus on his salary if he fulfills his plan or assignment, and that he also receives one and one-half per cent of the value of products that are manufactured over and beyond their annual quota.

They have been able to increase their output about 25 per cent each year with improved methods and better labor productivity. Most of the work done in this plant is performed on a piece-work basis.

We had an opportunity to get a first-hand look at Russian automotive production techniques at the Gorki Automobile Plant and at the Stalingrad Tractor Plant. At neither place did we find over-all production techniques on a par with automotive production techniques in this country.

The Gorki plant makes two models of cars and several models of trucks, including an agricultural car which resembles our jeep. The passenger cars are the ZEM, which resembles an older model Buick, and the Victory or "Pobyetta," which looks like a reduced version of a Plymouth. The Victory is soon to be replaced by a new car, the Volga, for which the plant is now being retooled.

Anticipated improvement of performance of the Volga over the Victory is indicated by the following chart comparing specifications:

	Volga	Victory
Speed	130 KM per hr.	110 KM per hr.
Acceleration	16 Sec. to 60 KM per hr.	24 Sec. to 60 KM per hr.
Fuel Consumption	11½ to 12 liters/100 KM	12½ liters/100 KM
Horsepower	70	52
Torque	17 KM	12½ KM
Displacement	2.45	2.12
No. of Cylinders	4	4
Compression Ratio	6.6	6.2
Fuel Required	70 Octane	66 Octane
Engine Fuel Consumption	220 grams per HP hr.	265 grams per HP hr.

Note: The fuel consumption of the Victory figures 19 miles per gallon at about 30 MPH.

So far the factory has produced only one unit of the Volga, but it has passed state tests and is now undergoing further factory tests. The Volga will have an automatic transmission, the first to be produced in the Soviet Union. The Volga automatic transmission is a planetary gear unit with torque converter. There are two manually selected positions in addition to reverse. The low position has single speed, and the drive position has two speeds. In the high speed, the gear ratio is 1 to 1 and 1.55 to 1. The low speed is 2.15 to 1. We were told the efficiency was 92 per cent at 60 kilometers per hour (about 38 MPH). The car will have a knee-action front, and rear end suspension similar to that on American cars.

The main product of the factory is a one and a half-ton truck. However, they make another truck called an "A-1" which is comparable to a Ford five-ton truck. Three other lines of trucks, the GAZ-51, the GAZ-69 and the BAZ-MM, complete the truck line.

Of the 1,000 vehicles produced per day, 780 are trucks, 120 are passenger cars, and 100 are agricultural vehicles. We were told that all trucks are destined for ownership by the state. The heavy truck production for State use stems from a Soviet rule that no one may employ another person where that employee would create a profit for the employer. This means that one can employ only domestic help, or that only an immediate family can work on the same project outside state ownership. Such a situation, of course, makes the necessity for privately owned trucks practically nil.

The Gorki plant buys its automotive instruments, batteries, rubber, trim, leather, and other items from other plants within the Soviet Union. They make their own frames and wheels.

We saw one mechanical operation for push rods

that was unique. They turn a small bar on a screw machine and upset the end into a recessed head. These parts are fed automatically into a rotary table where they pass under an induction melting unit. A high chrome alloy is melted and poured into the recessed head to form a composite metal push rod. These push rods are made on semi-automatic machines, and the high chrome alloy, poured into the recessed head, Rockwells from 58–60 on a "C" scale.

The engine line used a few transfer machines made by the Ordzhonikidze Plant and NATCO of U.S.A., and there were several Excello machines. There were three engine lines, but it appeared that they were holding one line in reserve. We noted that most of the movement of parts in the engine line was accomplished with roller conveyors, the only automatic handling being done at the transfer machines. The engine assembly line was arranged very well by U.S. standards of possibly ten years ago. This particular portion of the plant was clean and well lighted. They are still assembling the engines on a non-automated buggy type conveyor, and they do not have a synchronized supply line feeding the assembly. An overall impression of the machine shop and the engine assembly lines would indicate a lack of modernization and would also indicate that they are far behind by American standards. When I refer to American standards in an automobile plant, I make the comparison with the top line, modernized factories of the United States.

Not having seen the final assembly line and the press shop, I was obliged to complete my story involving this portion of the trip from notes and reports by Dr. Hall and Dr. Brandt. The following portion was supplied by Dr. Hall:

The plant is very well equipped with presses and is in the process of installing others. They are presently installing approximately 12 PELS (East German) presses of 400- and 800-ton capacity. There is one press of 1,200-ton capacity to be installed. These presses were being used for making parts for both cars and trucks.

Whereas the truck line was busy and appeared to be efficient, the passenger car line was slow and gave a deserted feeling. Car bodies were held together with jigs and welded, the car having an integral frame. The assembly line for the Victory was in three general parts. The first part was a rotary line, in which the car was held on a movable stand approximately six feet high. On these stands the axles were placed and the body assembled. The car was lifted off this line and placed on a second rectangular line approximately five feet high. Workers could be both on the top of the line along the car, or underneath. The third line was a movable plank at the end of the second line. There was also another line which was a return line and similar in form to the second line above. This line was said to be for adjustments, although we questioned this since there was little or no work being done on this line. There were a number of cars off the line waiting for additional adjustments. The capacity of the factory line is 150 cars per day, which may be further increased, they said.

The die shop in the plant seemed to be very well equipped. There was a temperature controlled room for jig borers, in which there were more than ten ZIP Swiss jig borers. There were also two Giddings and Lewis borers and one Pratt and Whitney borer. All appeared to be in good shape. In the die shop several very large milling machines were employed. One was a horizontal bar, bridge-type machine, approximately 30 feet in height, used in roughing out dies. There was no copy attachment.

There were several Keller-type machines—perhaps four to six. The die shop appeared to employ about 100 people. They have investigated high-frequency ignition. Mr. Mazorkin said that a unit from Bosch had been studied. It was not considered practical—too complex and subject to vibration. They are employing bonderizing on the GAZ-69 and expect to employ it on the Volga. They are cementing the brakes to the bands on all cars. They employ a fuel pump of the diaphragm type, operated with the cam shaft. This is used on all cars.

They stated that the automobile factory in Moscow is producing 120 cars per day. During the next five-year plan, the Gorki plant expects to double production.

The plant also has a bicycle factory but expects this will be discontinued in the future. The bicycle line was on the top floor of one of the buildings and was quite well lighted, particularly in comparison with the rest of the plant. It was operated primarily by young people 18 to 20 years of age, mostly girls. They are producing 2,200 bicycles per day. They make their own brakes, which appeared to be somewhat cheap and light. The frames are welded together by an interesting process, which we did not see but which was described to us. The frame members are pressed together with a copper alloy slug, and the end of the frame is dipped in a hot salt bath until the alloy melts and welds the frame together.

In general, our impressions of the plant were the following:

Tooling was old, but well kept.
The factory plant was poorly lighted and poorly kept up.
The truck assembly line appeared to be very effective.
The automobile assembly line appeared to be almost dormant.
The shop superintendents we met were competent.
The Assistant Chief Designer Mazorkin, who won the Stalin prize, was alert, intelligent, and very capable.
The Director of the Plant was a very impressive individual . . .
Except for the valve head fusing operation, there was nothing novel in a production operation.
The workers appeared to work much more enthusiastically than workers in U. S. plants.
There was considerable lost motion because materials were not brought directly to the individual who, in some cases, was using old equipment.

At the Gorki plant the average worker receives 975 rubles per month; foremen, 1,200 to 1,300 rubles per month. The section head receives approximately 20 per cent more; the shop head receives again approximately 20 per cent more; the plant head receives another 20 per cent; and the director's salary was not indicated.

The following portion was supplied by Dr. Brandt:

A discussion was held with Mr. Alexev and Mr. Mazorkin. Mazorkin is the designer of the Volga.

Some time ago, they changed their electrical systems to 12 volts to facilitate starting in cold weather. They have used sealed beam headlights since 1946 and have no problem with the life of bulbs on the 12-volt systems.

There are norms for all workers, including day workers. Norms are the responsibility of the Department of Organization of Labor. Bonuses are paid for exceeding the norms.

Labor unions organize the workers to fulfill tasks, are responsible for education, for paying sick benefits, distributing maternity benefits, various aid programs, rest houses and sanitoria. The labor unions have a budget of their own and are supported by dues paid by the members. It was claimed there have been no strikes since 1917. The unions watch safety problems and it was emphasized by the directors that the unions help them run the plants.

The plant is practically a town in itself with homes, schools, colleges and technical schools where many of the workers are enrolled with technical diplomas as their aim. Plants of this nature have their

own recreational facilities which are usually housed in what they call "recreation palaces." These buildings house swimming pools, gymnasiums, and auditoriums where they produce their own ballets and operas. They also have reading rooms and libraries and are the central point for the recreational activities of the plant workers.

The Stalingrad Tractor Plant was built in 1930 and operated as a wheel-tractor manufacturing plant until 1937 or 1938. Since that time the plant has made caterpillar-type tractors and strategic war materials. We were told that the International Harvester Company was responsible for a great deal of the original planning and installation work in the plant.

In 1950 the plant began production of Diesel caterpillar tractors with 54-horsepower engines and five-speed and reverse type transmissions. It is producing about 80 such tractors per day. Prior to the war, a more varied line of products emanated from this plant.

Some of the specifications given on the current model tractor stated that the engine had 125-mm. diameter bore with a 152-mm. piston travel. Their normal engine torque is 36 KGM at 1,300 RPM. The maximum torque is 18 per cent to 20 per cent above its normal requirements. This extra power permits the overcoming of shocks and, in tests, the engine shows a flat curve with 38 to 54 horsepower. It was stated that by being over-powered, there was an accomplishment of fuel economy and a provision for ease of operation. By using indirect injection, they have provided for the use of almost any type of fuel. If direct injection were used, a much more careful selection of fuel and higher degree of manufacturing accuracy would be required. The tractor is started with an auxiliary, gasoline-fueled, rope-starting engine. A special clutch transfers the energy from the starter engine to the flywheel of the tractor engine. They have designed the tractor so that it is adaptable for agricultural, industrial and lumbering usage. A heavy front cross beam made of a steel casting not only provides an excellent support, but also acts as a counterbalance as well. The tread on this tractor has to support a weight of from .34 to .37 kilograms per square centimeter. They also stated that their caterpillar tractors are not subjected to a "slope slip" which is often encountered when plowing on the side of a hill. These tractors sell for about 15,900 rubles.

A new tractor that they intend to produce, known as a "swamp" tractor, will be equipped with treads that are required to support only .19 to .20 kilograms per square centimeter. We were told that the swamp tractor can negotiate swampy terrain successfully where an individual walking would bog down.

We were advised by the Director that they had plans for making what they called a hill-type tractor sometime during 1956. They explained that the tractor would have the advantage of not turning around, but by reversing the implements, they would be able to plow or cultivate in either direction. This particular tractor will have five speeds forward and five speeds reverse.

We visited their foundry where steel castings are made. They do not have a foundry for cast iron at this location. Their metal is melted in electric furnaces. The melting section of this foundry was in an extremely poor housekeeping order. Discarded or unwanted material of various types, including equipment, was permitted to lie about at random throughout this foundry. Their pouring and shake-out lines were in much better order and the type of equipment used in the moulding processes was somewhat similar to that used in the States. I was not favorably impressed by their foundry and later made this statement to the Director and personnel of the plant.

In going through their machine shops, we found certain areas equipped with modern transfer type machines, many being of new and apparently efficient design. However, a great deal of the manufacturing is done on standard machines, some of which appeared to be quite old. When we reached their assembly line, we noted better housekeeping, and the assembly stations appeared to be arranged very efficiently. In this assembly line, we counted some 47 stations and I noted that there were about 40 people working on the line.

During this tour, the Director told us that by meeting their schedules, they had received awards which were separated into two divisions of 50 per cent each. Enough was received from one 50 per cent to pay each worker approximately 800 to 900 rubles per quarter as a reward for the plant accomplishment. The other 50 per cent went to the Director who was obliged to share his portion with the welfare and medical programs of the employees.

The Director of this plant is a Mr. Alayev. Other officers at this plant are: Mr. Sidelnikov, Chief Engineer; Mr. Kotelnikov, Chief Metallurgical Engineer; Mr. Agafonov, Chief Technician; Mr. Korolev, Engineering Mechanic; Mr. Polumordvinov, Personnel Director; Mr. Glazov, Mechanical Engineer.

The Russians told us they have a completely automated piston plant in Siberia, but time did not permit a visit there. However, the chief engineer of the plant came to Moscow and brought with him drawings and photographs of lines and processes which he showed me.

The drawings and pictures indicated that the entire process of manufacturing aluminum pistons is automated, except the melting of metal which is a manual operation. After melting, the metal is poured automatically at the beginning of manufacture. Then the pistons continue through a metal treating furnace where they remain five and a half hours at 250° C for stabilization. Then they go on through machining and inspection—which requires no manual assistance in operations—until the finished product emerges at the end of the line. This automated line was designed and all machine tools were built at the ENIMS Plant mentioned earlier in this report, and then installed in the Siberian plant.

Another key factor in the future development of the Russian industrial potential is the country's educational system. There are 33 universities and nearly 1,000 separate colleges with a total enrollment of between 1,600,000 and 1,800,000 students. An unusually high percentage of the students—more than 50 per cent—are enrolled in science and engineering courses. We visited Moscow State University where we were able to see something of the quality of instruction.

The university is made up of 12 departments, with six in natural sciences and six in the humanities. The humanities include departments of history, philology, law, philosophy, economics and journalism. Natural science departments are mathematics, physics, chemistry, biology, geology and geography. No engineering is taught at Moscow University, but students in the sciences may take up engineering later at special technical colleges.

Ninety-six per cent of Moscow University students receive stipends which run from a minimum of 290 rubles per month during the first year to a maximum of 450 rubles per month during the fourth year. In addition, those receiving excellent marks get a 25 per cent bonus. There are also 225 scholarships at the Moscow University for the most talented students. These scholarships carry stipends of between 450 and 750 rubles per month. Approximately 58 per cent of Moscow University students are enrolled in natural sciences, with 30 per cent in mathematics, physics and chemistry. Russian students appeared to be more serious and to work harder than American students.

The school auditoriums, laboratories, living quarters, halls and classrooms are not only beautiful, but appeared to be planned in a very practical manner. Equipment in laboratories was especially noteworthy; it was better than the average in this country and as good as the best.

The Academy of Sciences also plays a very important role in Soviet engineering. The academy has about 100 full members, or academicians, and other corresponding members. Several dozen research institutes come directly under the academy, and directors of these institutes are nearly always academicians. Usually these directors have corresponding academicians on their staffs. An academician is one who has contributed some outstanding scientific development to the Soviet Union. He gets a salary of 5,000 rubles per month just for being an academician. He is paid in addition for any other positions he may hold. A corresponding academician draws 3,000 rubles per month on the same basis. Some academicians are professors and some do straight research work.

In addition to the Academy of Sciences there are separate academies of pediatric science, medicine, agricultural sciences, art and architecture. Most of the Russian medical doctors are women.

Besides these organizations of higher learning, there are in the factories extensive training programs that give workers an opportunity to get high school and technical school educations.

At the beginning of our trip we were told by members of the U. S. Embassy and by our interpreter that the Russians would not appreciate flattery, but actually preferred us to make accurate and factual criticisms of their plants and processes. At the end of our tour we met at the ministry to give the ministry personnel an opportunity to question us about what we had seen. Those attending this meeting were as follows:

A. A. Myachev, Assistant to the Minister.
N. A. Volkov, Deputy Head of the Technical Counsel of the Ministry.
P. S. Bulgakov, Head of the Machine Building Division.
V. I. Loskutov, Head of the Technical Administration.
N. V. Dolzhenko, Deputy Chief of the Production Division.
V. P. Lukin, Chief Engineer of the Instruments Division.
V. M. Trapenznikov, Correspondent-Member of the Academy of Sciences.
V. G. Borisov, Head of the Machine Tool Building Division.
I. P. Gusev, Head of the Automobile Manufacturing Division.
A. P. Vladziyevski, Director of ENIMS Institute.
A. A. Pospelov, Chief of the Economic Section of the Ministry.
I. A. Sidorov, Senior Engineer of the Ministry.
P. N. Spiridonov, Senior Engineer of the Ministry.
L. F. Hodrokof, Translator of "In-tourist."

During this meeting, members asked us to detail faults and shortcomings we had noticed. When we did so the ministry received our comments graciously and seriously, writing down each criticism very carefully. The Russians seemed pleased that we offered our criticism in good faith and without intention to belittle. Their eagerness to improve industrial conditions and industrial techniques is matched only by their aggressiveness in attacking problems involved in bringing their industry abreast with manufacturing conditions in other countries. Their attitude indicated they still look upon the United States as a leader in modern industry, and it appears that their aim is to equal or better any industrial processes we have now.

During our meeting with the ministry, we inquired as to their progress in developing transistors. The Director of the Institute of Telemechanics and Automation was present and stated that they were developing transistors of both silicon and germanium types. His answers were rather indefinite and we gained no particular information that would be conclusive. The ministry as a whole expressed a great desire for future meetings and future exchanges of engineers of the two countries. Practically all of the

ministry personnel are desirous of visiting the United States to study production and to obtain answers to problems with which they are now confronted. Work being done in Germany on ceramics, both for tools and for high temperature coating, was discussed at length.

During this meeting, Dr. Hall inquired whether the type of complete automation that we had seen at the Kaganovich Plant had been used extensively throughout Soviet industry. The Director of the meeting explained that one of the best applications of automation other than the Kaganovich Plant was the Ulynovak Piston Plant. He said they also had a completely automated plow plant and that many of their plants where bolts, nuts, screws, etc. were made had been completely automated.

The Soviet system is not now geared to provide a standard of living comparable to ours in America, but production facilities are being expanded rather rapidly. At current graduation rates, within a few years the Soviets will have a much larger pool of trained engineers and technicians than we, and they can put them to work solving the riddles of industrial expansion. It is entirely possible that they can rather quickly narrow the gap between their capacity and ours. They already have men who know how to improve their productivity and they are training thousands more.

"Already well-launched, automation will reach a crescendo under the impact of cheap and abundant power (from nuclear and solar energy). It will increase production, decrease costs, and make more goods and services available to more people. The transition will create problems of adjustment but ultimately it will free millions of people from arduous and hazardous work. It will increase employment, reduce hours of labor and increase leisure."—Predictions of future technology by General David Sarnoff.

VICE ADMIRAL HAROLD G. BOWEN,
U.S.N., Retired

REMINISCENCES

This is an address which Admiral Bowen, presently President and Treasurer of U. S. Ring Traveler Company, Providence, R.I., first Director of Naval Research and a past-President (1938) of this Society, made on 8 February 1957 at a dinner to commemorate the tenth anniversary of the establishment of the Office of Naval Research.

Note: All quotations are extracts from "Ships, Machinery and Mossbacks" by Harold G. Bowen, Vice-Admiral U.S.N. (Ret.) Princeton University Press.

ADMIRAL BENNETT, ladies and gentlemen, distinguished guests—I am happy to be here with you tonight to celebrate the tenth anniversary of the establishment of the Office of Naval Research. After World War I, there was considerable dissatisfaction expressed in Congress with the way the Navy had been handling, or rather didn't handle, the radio communication patent situation. It was alleged that inventions made by the Navy in this category were never patented by the Navy for government use. I advised Secretary Forrestal that the same situation must not arise after World War II and that every effort be made to safeguard the government's interest in basic Radar and other inventions being made by the Navy in the research and other laboratories.

Mr. Forrestal was very much interested in the subject and acquired the services of a well known patent lawyer, Mr. R. J. Dearborn, who at the time was President of the Texaco Development Corporation and Chairman of the Committee on Patents of the National Association of Manufacturers, to survey the policies and procedures of the Navy Department with respect to patents and inventions. A happier choice could not have been made.

Mr. Dearborn made the survey and submitted a report on 10 March 1944, together with the plan which became the basis for the reorganization of the Navy Department activities concerned with research, inventions and related matters. This report was accompanied by a draft under which an Office of Patents and Research would be established. Actually, Mr. Dearborn submitted three plans, but it was desired to proceed cautiously in order not to stir up the snake.

Office of Patents and Inventions:

"Many of the proposals set forth in the third plan of the Dearborn report were embodied in a directive issued by the Secretary of the Navy on 19 October 1944, under which there was established an Office of Patents and Inventions. This new office was charged only with certain functions concerning inventions and patents, and it was given no authority over the research activities of the Navy Department. While a small step and only a beginning, it was a fundamental step in that it took all responsibilities for patents from the office of the Judge Advocate General and placed them in a patent office under aggressive leadership."

Office of Research and Inventions:

"On 19 May 1945, the Secretary of the Navy issued a directive establishing, in his office, the Office of Research and Inventions. This directive, following the recommendation of the Dearborn report, provided for the appointment of a Chief of Research and Inventions to head the new office."

"Not until the Secretary issued the directive had an attempt been made to coordinate and centralize the research activities of the Navy, except for my own abortive attempt before Pearl Harbor."

"I was given broad powers with respect to coordination and conduct of Naval Research activities and administration of activities relating to patents and inventions. The directive also provided for the incorporation, under the Chief of Research and Inventions, of the Office of Research and Development, the Naval Research Laboratory, and the Division of Special Devices. Another directive, dated 4 February

1946, set forth the procedure to be followed by the Bureaus, so that the negotiation and execution of Naval Research contracts would be coordinated by the Office of Research and Inventions. On 29 September 1945, the President issued Executive Order No. 9653, under authority of the First War Powers Act, in order to eliminate any possible doubts concerning the authority of the Secretary of the Navy to make effective the organization changes referred to above."

In plain language, the Executive Order was necessary to prevent any disaffected person from making an end-run up in Congress and knocking the whole research reorganization into a cocked hat.

"On 1 August 1946, Public Law 588 of the 79th Congress created the Office of Naval Research in the Office of the Secretary of the Navy, with Bureau rank, and I became its first Chief, by and with the advice and consent of the Senate."

"Thus the Office of Research and Inventions, under a new name, acquired statutory authority and its own appropriation, and my dreams for Naval Research were realized. In Washington, one cannot accomplish anything without a statute in front of him and an appropriation behind him."

Founders:

"I have already mentioned the name of Mr. Dearborn as the initiator of the plans which resulted in a chain of events ending in the statutory establishment of a research center in the Office of the Secretary of the Navy. Others without whom this achievement could not have been accomplished were Rear Admiral Lewis L. Strauss, U.S.N.R. (now Chief of the Atomic Energy Commission), who was my ever present help in time of trouble; and the Honorable H. Struve Hensel, (then) Assistant Secretary of the Navy under Mr. Forrestal (and a great enthusiast for research). Great credit is also due to (the irrepressible and incompressible) Rear Admiral Luis de Florez, U.S.N.R., whose Division of Special Devices of the Bureau of Aeronautics became a part of the new office. He contributed many of the key individuals of Special Devices to the main office of the new organization, and he obtained from the Bureau of Aeronautics a transfer of funds from that Bureau to the new organization amounting to $24,650,000."

Organization:

"At the very beginning I had some fundamental decisions to make regarding personnel and contracts. For years naval officers and scientists had worked together harmoniously and efficiently at the Naval Research Laboratory, and I decided to use the same system in my new office. I selected all my division heads from among the scientists. I assigned Naval Officers to all administrative positions. I procured the services of Dr. Alan T. Waterman of Yale University (now Chief of the National Research Foundation) as Chief of all our scientists, and he did an excellent job, not only in science but in the necessary coordination work between science and administration." As a matter of fact, a great deal of the early success of ONR was due to his experience, wisdom and the fact that he always had his feet on the ground. "The work on contracts for research was original and pioneering. In usual Government contracts, one can see what is bought—it is tangible, the quality and quantity have to be as described in specifications, and, if machinery, it works or it doesn't work. Before the contract is sent to the Comptroller General of the United States to validate the payment, it must bear a certificate that value has been received."

"Now we must let contracts for the intangible, namely, Research. Obviously there could not be any specifications. Results or end products would be opinions, discoveries and possibly inventions, or even reports that the problem had reached no conclusion and the work should be discontinued. The necessary type of contract was conceived by the late Captain Robert D. Conrad, U.S.N.; Commander James H. Wakelin, U.S.N.R.; and Commander John T. Burwell, U.S.N.R.; as a result of their experience with contracts in the Office of Coordinator of Research and Development before that office was absorbed by the Office of Research and Inventions. They were assisted by Commander H. Gordon Dyke, U.S.N.R.; Commander Eugene Krause, U.S.N.R.; and Commander Bruce Old, U.S.N.R."

"Captain Conrad was the administrative head of the Scientific Research Division. A great deal of the original success of the Office of Naval Research was due to his extremely likeable disposition, coupled with an active and brilliant mind. His death from natural causes at an early age was a great loss to the Navy."

"Forty-eight of these contracts were shortly let with universities and non-profit institutions, and twenty more with commercial concerns."

"It was I who had to take the responsibility for letting these contracts which were not provided for by law. I believed that the emergency justified the action, but I was careful when the opportunity presented itself to tell Congress, the Bureau of the Budget, and the Comptroller just what I was doing so that they would get the news first—a very practical approach to a problem in Washington."

"I did have trouble explaining to the Bureau of the Budget and the Appropriations Committee, when I had hearings on my 1946 budget, what Research was. I explained in response to questioning that, if you could write specifications for a research problem, there was then no research, it was engineering. In an attempted witticism, I told them that if you knew what you were doing, it wasn't Research."

"As a result of all this, the law which established the Office of Naval Research contained a provision authorizing the Secretary of the Navy and, by his direction, the Chief of Naval Research and the Chiefs of the Bureaus to enter into contracts and amendments and modifications of contracts for services and materials necessary for the working and securing of

reports, tests, models, apparatus, and for the conduct of research without regard to certain statutory limitations, etc. This incident further confirmed my experience that, if you know what you want and can explain it properly, you will have no trouble getting it from Congress, provided, of course, that your request is reasonable."

Branch Offices:

"The Special Devices Division of the Office of Naval Research long had had branch offices in Boston, New York, Chicago, San Francisco and Los Angeles. When the Special Devices Division joined the Office of Naval Research, I merged the branch patent offices (which I had already established) with the Special Devices branch offices to form the new branch offices of the Office of Naval Research. A branch office was established in London for the purpose of becoming familiar with the general course of research in England and on the Continent. It did not handle secret matters: it was not a cloak and dagger club."

Staff Organization:

"I was assisted by an administrative branch under Captain (now Rear-Admiral) Martin J. Lawrence, U.S.N., which planned, coordinated, and controlled general administration and management services; a material branch under Commander Mason which drew up all research contracts (the Patent clauses of procurement and research and development were skillfully handled by Commander Ernest F. Vanderstrucken, U.S.N.R.); a budget branch under Lieutenant Commander C. H. Helsper, U.S.N.R., which was responsible for proper and legal expenditures of research funds, for avoiding of any deficits, for compliance with statutory limitations and restrictions on the use of research funds and material, and for the preparation of the budget estimates; a field service section under Lieutenant Commander Paul Busse, U.S.N.R., which supervised administrative and operational procedures of branch offices; the office of General Patent Counsel for the Navy under Captain Ralph Chappell and later Captain John H. Austin, U.S.N.R., which was a patents section; an inventions section under Dr. Murray O. Hayes, which analyzed inventions submitted by Navy personnel and others; a publications section under Mr. Earl Nash, which furnished information regarding the Navy's research programs and ONR activities; a public works facilities section which was responsible for matters in the Office of Research and Inventions pertaining to real estate, leases, and construction projects; a scientific personnel branch under Mr. A. H. Hausrath, which was concerned with activities pertaining to attracting, developing, and retaining highly creative and productive scientists in the Naval Research Laboratory's establishment; personnel administration (military and civilian) under Commander G. T. Calloway, U.S.N.; a planning division under Captain Conrad, which was responsible for planning and recommending the placement of, and directing contracts for fundamental research in civilian and Government establishments, and for placing and coordinating research within the Naval Establishment."

"One of the greatest achievements of the Office of Naval Research was the establishment of the Scientific Personnel Division under Mr. A. H. Hausrath. When demobilization took place, the Office of Naval Research had the only list of young scientists who had been drafted and were now being discharged and would be available for Government laboratories and industry. By that time the list contained 2,000 names, and professors, directors of laboratories, and industrial organizations constantly availed themselves of this list and often interviewed prospective candidates. I never saw any activity so speedily organized and put into production as the Office of Naval Research."

Talk about Minerva, full grown and fully armed springing from the brain of Jupiter, why that was peanuts!

In effecting this organization, Captain Lawrence was ably assisted by that dynamic and irrepressible operator, Commander Virgil Wiese, U.S.N.R. Lawrence, Conrad and I were the only Regulars in the entire organization. All others were Reserves and civilians. The Reserve Officers and civilians may take unlimited pride in their splendid performance.

In the appraisal of past events, we can only evaluate such events by consideration of the climate in which they took place.

Climate:

A decade ago, when the Office of Naval Research was established, there was no such appreciation of the value and possibilities of research, basic or applied, as exists today. In some institutions of learning here and abroad work in basic research was underway. Research was underway in such government laboratories as Bureau of Standards and the Naval Research Laboratory. Some commercial corporations, for example, Bell Laboratories, General Electric and Westinghouse, fully understood the value of applied research and were busily engaged in it. I do not think that any one, anywhere at that time understood that research, basic and applied, was vital to the very existence of a modern industrial state such as the United States of America.

In 1939 when I became Director of the Naval Research Laboratory, one of our leading calumniators stated in his column that I had been banished to the Naval Research Laboratory so that I could not do any more harm to the Navy. The "harm" referred to, incidentally, was the introduction of high pressure-high temperature steam into all naval vessels, together with the modernization of all the mechanical and electrical machinery aboard ship. The sad part of it is that there was a great deal of truth in the columnist's statement. The job of Director was not regarded in the Navy as much of a job. The laboratory was located in an unfinished part of the District of Columbia, between St. Elizabeth's (a mental hospital) and the Sewage Disposal Plant. Obviously, I was in bad odor.

One time later at a meeting of the Secretary of the Navy's Council, I announced the great possibilities of radar in defense against aircraft. A distinguished aviation Admiral whispered in my ear, "We will fly low and evade it."

Still later, in April 1939, when I announced to the same Council that atomic fission had been accomplished and I predicted the development of atomic weapons and atomic propulsion and furthermore revealed that I had allocated funds to the Naval Research Laboratory to undertake the concentration of Uranium-235 by the thermal diffusion method, there was no comment or discussion that I can recall.

This thermal diffusion method of concentration was the famous Abelson-Gunn process, named after its originators, Dr. Ross Gunn and Dr. Philip H. Abelson, at that time both at the Naval Research laboratory. This process was later to take the heat off Manhattan Project in producing the first atomic bomb. As a matter of fact, Dr. Lyman Briggs, then Director of the Bureau of Standards and Chairman of President Roosevelt's secret atomic energy committee, wrote me an unsolicited letter, dated January 10, 1956, at Washington, D.C.:

> Dear Admiral Bowen:
>
> I think of you often.
>
> If it had not been for your generous cooperation and foresight in making funds available at a critical time, the work on the atomic bomb would have been set back at least six months. I shall always be grateful to you.
>
> Sincerely yours,
>
> (Signed) Lyman J. Briggs.

I merely recite these instances of the contemporary low estimates of the value of Research to recreate, if possible, the unfavorable climate in which the late James Forrestal and others began their early moves to ultimately establish the Office of Naval Research, whose establishment we are celebrating this year.

I am very proud to recall my association with that extraordinary collection of Regulars, Reserves and civilians who pioneered with me in building and launching the Office of Naval Research.

I wish time had permitted me to have mentioned everyone involved.

Although it is estimated that the United States spends approximately six times as much on research and development as Great Britain, a percentage comparison based on gross national product more accurately reflects the comparable efforts of the two countries. The United States spends the equivalent of 1½ per cent of its gross national product for total research and development, as compared with 1¾ per cent in Great Britain. One-half of the total expenditures in the United States are furnished by the Federal Government, as contrasted with three-fourths in Great Britain. One further comparison shows that in the United States one-third of the research effort is in direct support of national security, whereas in Great Britain 60 per cent is for defense purposes.

LIEUTENANT COMMANDER ROBERT S. BURPO, JR., USNR

CONTROL OF CARBON POTENTIAL IN FURNACE ATMOSPHERES

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INTRODUCTION

THE HEAT treatment of iron and steel in controlled atmospheres is one of the important industrial processes of our modern technology. The development of the techniques, furnaces, atmosphere generators and of the control equipment has indeed been rapid during the past quarter century.

The use and understanding of furnace atmospheres with controllable carbon potentials is based on the application of certain principles of thermodynamics. Gibbs' phase rule and heterogeneous equilibria are two of these principles. Carburizing, carbon-restoration and neutral or "bright" hardening are three widely used processes and they all depend on the control of the carbon potential of their respective atmospheres. Of these, carbon-restoration is the newest process; it was introduced during World War II and it has been improved and refined during the post war years. This paper will survey the utilization of the phase rule as one of the principles of heterogeneous equilibria in the control of these three important metallurgical processes.

Intimately associated with any detailed study of carburizing is the phenomenon of diffusion (a rate process) and its effects will not be considered in this study. This paper is concerned primarily with the principles by which the carbon potential of an atmosphere can be controlled for useful purposes. The regulation of the amount of carbon available in a given atmosphere at the hot steel-gas interface is the topic to be considered. The diffusion of the carbon after its solution in the steel, although of no less importance, is considered to be outside the scope of this present paper. Likewise, the interactions of such active gases as nitrogen (as typified by the newer carbonitriding or nicarbing process) in the furnace atmosphere are not considered.

The thermodynamic system composed of a multicomponent gas and the steel charge inside a heated furnace can be described by specifying the values of a series of independent variables; the magnitudes of the dependent variables of the system are thereby fixed. The application of Gibbs' phase rule to such a situation determines the number of the possible variables that must be independent. The choice of which individual variables will be the independent ones is based on a study of the particular system and of the applicable principles of heterogeneous equilibria. If the system can be specified unambiguously, then, given suitable control apparatus, it can be controlled. The simplifications introduced by both the phase rule and the use of the appropriate equilibrium constants make control of these systems practicable because they reduce a complicated quantity of independent variables to a single variable, the control of which governs the entire system.

FURNACE ATMOSPHERES—THEORY

Gaseous Constituents of Atmospheres

Inside a furnace used for the heat treatment of steel parts the following* reactions may occur:

$$Fe + H_2O \rightleftarrows FeO + H_2 \quad (1)$$
$$Fe + CO_2 \rightleftarrows FeO + CO \quad (2)$$
$$CO + H_2O \rightleftarrows CO_2 + H_2 \quad (3)$$
$$CH_4 + CO_2 \rightleftarrows 2H_2 + 2CO \quad (4)$$
$$Fe + CO + H_2 \rightleftarrows (Fe, C) + H_2O \quad (5)$$
$$2CO + Fe \rightleftarrows (Fe, C) + CO_2 \quad (6)$$
$$Fe + CH_4 \rightleftarrows (Fe, C) + 2H_2 \quad (7)$$
$$2CO + O_2 \rightleftarrows 2CO_2 \quad (8)$$
$$CO + 3H_2 \rightleftarrows CH_4 + H_2O \quad (9)$$

* These nine reactions are assumed to represent all those that might occur under normal operating conditions. If there were any additional ones, they would have to be included in the following analysis or it would be invalid without them.

Each of these reactions is reversible depending on the ambient conditions, and its direction is determined by the LeChatelier-Braun principle.† All of these reactions need not occur at the same time nor are each of these equally desirable or beneficial. Reactions (1) and (2) are symbolic of the formation of scale and, hence, often represent undesirable conditions. Carburizing and carbon restoration reactions involve mainly reactions (5), (6) and (7). Reactions (5) and (6) are the more important ones taking place within a furnace used for neutral hardening.

An analysis of a furnace atmosphere containing eight or ten (or more) constituents and having these connected by five or six equilibrium reactions (that may proceed in either direction) can be complex and unwieldy. By the application of the principles of heterogeneous equilibria, simplifications can be made that enable metallurgists and metallurgical engineers to understand and to control furnace atmospheres with a minimum of effort.

The following, then, is a summary of the studies of and information regarding furnace atmospheres as applied to the practical heat treatment of iron and steel.

Carbon Potential

Basically, the problem is one of carbon concentration control in the heat treating furnace. The so-called inert atmospheres (for reheating, for forging, for bright annealing, or for hardening) are only inert as long as they permit no carburizing nor decarburizing (as well as no scaling); in other words an inert atmosphere should be in equilibrium with the carbon concentration of the steel being treated. For carburizing, the primary function of the atmosphere is to increase the carbon concentration in the surface of the steel. And for carbon restoration (often accomplished along with heating for forging or for hardening), the desire is to restore the carbon concentration to its original value in the surface of the steel (the furnace atmosphere then must have a definite and controllable carbon potential). The carbon potential of a furnace atmosphere is its carburizing ability (or the concentration of carbon in steel with which the atmosphere will be in equilibrium).

Application of the Phase Rule

When steel is being heat treated in a controlled atmosphere furnace, there are a maximum of four phases present (unless scaling or carbon deposition —sooting—takes place; then there will be five or six phases in the system): (1) the gas, (2) ferrite, (3) austenite, (4) cementite. Since pearlite is the lamellar mixture of ferrite and cementite, and ledeburite is the cementite-austenite eutectic mixture, these are not separate phases.

The term "equilibrium" has been used several times previously and it is stated that Gibbs' phase rule is only applicable to equilibrium states. A piece of steel in a furnace under equilibrium conditions will undergo no net change in its carbon content, neither will it be oxidized nor reduced, and its temperature will remain constant.

Carburizing is not an equilibrium process (it is a rate process) for the surface carbon of the steel is increased in response to the carbon potential of the furnace atmosphere; at the same time carbon is diffusing inward along a surface-to-core gradient. Equilibrium conditions are established when the change in carbon concentration at the surface of the steel is zero. If a 0.20 per cent C steel is being carburized in an atmosphere having a 1.2 per cent carbon potential, the surface will acquire a case analyzing approximately 1.2 per cent carbon and this carbon concentration will not change with time after equilibrium has been established. A neutral atmosphere is, theoretically, in equilibrium with the material being heated so that neither carburization nor decarburization, scaling (oxidizing) nor reduction takes place. And for carbon restoration, the steel being treated acquires a surface carbon concentration equal to that at the core (and the same as the original surface carbon concentration before decarburizing occurred.) In this process the furnace atmosphere has a carbon potential equal to that of the steel prior to decarburization—and when equilibrium conditions occur within the furnace, the steel has been restored to its original carbon content and further time at temperature will not alter its analysis.

Analysis of a Simple Atmosphere

If steel were being treated in a furnace containing a simple atmosphere consisting solely of CO and CO_2, the reaction at the surface of the steel would be

$$Fe + 2CO \rightleftarrows (Fe, C) + CO_2. \qquad (6)^*$$

Let us assume that the concentration of CO in this atmosphere is high enough so that the reaction represented by equation (6) can only proceed to the right; i.e., no scaling takes place.

For the sake of concreteness, consider that the steel being treated is 0.50 per cent C and that it is being heated at 1500° F (816° C). These data, then, determine the point on the iron-carbon diagram, Fig. 1, representing equilibrium conditions in the furnace. Obviously the variables needed to specify unambiguously the state of this system are:

1. The temperature of the system.
2. The pressure on the system.
3. The C: Fe ratio in austenite.
4. The CO: CO_2 ratio in the gas.

Reaction (6) describes a three-component system, and the iron-carbon diagram, Fig. 1, indicates that the particular process under discussion occurs in a two-phase (austenite-gas) area. With these two parameters known, Gibbs' phase rule can be employed to establish the number of independent vari-

† See any standard text on physical chemistry for a discussion of the LeChatelier-Braun principle.

* Equation (6) is one (of many) symbolic ways of writing the over-all carburizing action. As a result of his tracer studies of the mechanism of carburizing, J. K. Stanley (1) uses this reaction, see also reference (4). It has been stated (2) that the carburizing reaction takes place in two stages: $2CO \rightleftarrows CO_2 + C$ and $Fe + C \rightleftarrows (Fe, C)$. When calculating the equilibrium constant for this process, the two subsidiary equations are added and their individual equilibrium constants are multiplied to find that for the overall reaction.

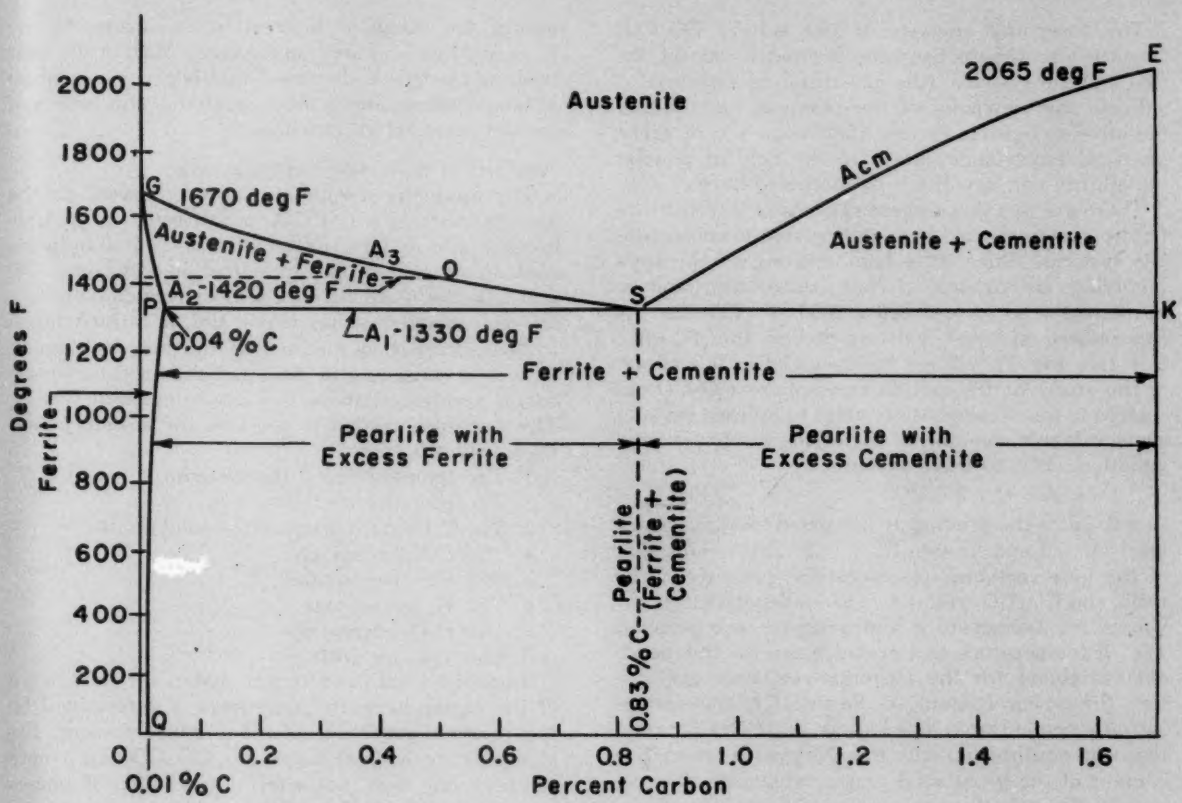

Figure 1. Iron-Carbon Diagram (14).

ables which are required to specify the system unambiguously. The phase rule is summarized in equation (10):

$$V = A - B + 2 \qquad (10)$$

where V is the number of independent variables, A is the number of components in the system, and B is the number of phases. For the simple process being described A=3, B=2 and hence, V=3. This means that any three of the four variables listed above can be selected as independent and the fourth is then fixed. If the temperature (1500° F in this example), the pressure (commonly one atmosphere) and the carbon content of the steel (C:Fe ratio in austenite) are the three independent variables that can be selected to satisfy requirements, there is only one value of the $CO:CO_2$ ratio in the furnace atmosphere that will be in equilibrium with these conditions.

A different group of three independent variables could have been selected. Suppose that it was desired to carburize some steel parts at 1650° F (890° C) in this simple $CO\text{-}CO_2$ atmosphere. If the atmosphere composition were known (i.e., if the $CO:CO_2$ ratio were established), what carbon content would be found in the surface of the steel being treated? The independent variables would then be: temperature, pressure and the $CO:CO_2$ ratio. The equilibrium diagram (Fig. 1) will give the C:Fe equilibrium ratio that will be established in the steel (neglecting any diffusion effects) regardless of the time at temperature (as long as equilibrium conditions have been established) and independent of the initial carbon content of the steel.

The equilibrium constant for the simplified atmosphere under discussion, reaction (6), can be expressed as

$$K_6 = \frac{A_c P_{co_2}}{A_{Fe}(P_{co})^2} \qquad (11a)$$

where P_{co} and P_{co_2} are, respectively, the partial pressures of CO and CO_2, A_{Fe} is the activity of austenite (and is equal to unity) and A_c is the activity of carbon in solid solution in the austenite. Equation (11a) can be rewritten as:

$$K_6 = A_c \frac{P_{co_2}}{(P_{co})^2} \qquad (11b)$$

A survey of the experimentally determined equilibrium constants of various gaseous reactions, including that of equation (6), is contained in a study made by J. B. Austin and M. J. Day (3). Using known values for A_c and K_6 and substituting them in equation (11b), the ratio of $CO:CO_2$ that will be in equilibrium with a given carbon content of steel (at a particular temperature) can be computed.

The foregoing analysis of the simple $CO:CO_2$ furnace atmosphere has been limited to one of the two 2-phase systems (the gas-austenite system).

From the viewpoint of the practical metallurgist the other two-phase system (ferrite-gas) is of slight practical importance except in the field of powder metallurgy and it will not be discussed here.

There are two three-phase systems of interest: the ferrite-austenite-gas, and the austenite-cementite-gas systems. Since little heat treating of the type involving carburizing, carbon restoration and/or hardening is performed below 1350° F (733° C), the three-phase system* existing below the $A_1-A_{1,3}$ line (see Fig. 1) will not be discussed in this paper.

The study of the simple atmosphere $CO:CO_2$ as applied to the three-phase systems of interest leads to some valuable conclusions. Applying the phase rule, equation (10), to these systems:

$$V = A - B + 2 \qquad (10)$$

$A = 3$ (as in the previously discussed two-phase system), $B = 3$ and, therefore, $V = 2$. This means that of the four variables (temperature, pressure, C:Fe ratio, and $CO:CO_2$ ratio) two are independent. If the values for temperature and pressure are selected (i.e., if temperature and pressure are the independent variables) for the austenite-cementite-gas system, the carbon content (C:Fe ratio) of the austenite plus cementite is fixed as is the $CO:CO_2$ ratio that is in equilibrium with this. Now with the carbon content of the gross solid phase (austenite plus cementite) fixed, the proportion of austenite to cementite† is variable but not the carbon content of austenite. The carbon content of the cementite is, of course, constant at 6.7 per cent by virtue of its being the compound Fe_3C. Thus a large number of steel analyses (within the appropriate range on the iron-carbon diagram) are in equilibrium with one specific $CO:CO_2$ ratio at a particular temperature. This means that, with the equilibrium $CO:CO_2$ mixture, steels within the appropriate range of carbon content will neither be carburized nor decarburized whereas any other gas ratio will tend to either carburize the steel to 100 per cent cementite or to decarburize it to the value of carbon represented by the intersection of the appropriate isotherm with the A_{cm} line.

Similarly the situation in the ferrite-austenite-gas area of the iron-carbon diagram is analogous. From equation (10) there are the same number of independent variables as in the previous three-phase case. And, likewise, at any given temperature one $CO:CO_2$ ratio is in equilibrium with a range of steel analyses. Any deviation from this equilibrium gas mixture will result (if sufficient time is allowed) in either carburizing to 100 per cent cementite or in decarburizing to ferrite.

The only other area of the iron-carbon diagram within the range of interest in this paper is the $A_1 - A_{1,3}$ line—an invariant system. Most of the heat treating operations discussed in this paper take place at temperatures above this line, so that this case is of limited practical importance.

Analysis of a Complex Atmosphere

The foregoing discussion has been based on the assumption that a $CO:CO_2$ mixture was a possible furnace atmosphere. From an economic standpoint such an atmosphere is impractical. In addition to CO and CO_2 the usual furnace atmosphere contains hydrogen, nitrogen, water vapor and, if carburizing is to be accomplished, methane (CH_4) may be present. A system consisting of steel and the gaseous constituents mentioned above is a five-component system. The variables needed to describe the system unambiguously are, then:

1. The temperature of the system.
2. The pressure on the system.
3. The C:Fe ratio in one of the solid phases.†
4. The CO percentage.
5. The CO_2 percentage.
6. The H_2 percentage.
7. The H_2O percentage.
8. The CH_4 percentage.

Since the inert gas nitrogen makes up the balance of the atmosphere, its percentage is determined by the relative quantities of other gases present. Exchanging the original simple gas, $CO:CO_2$, for a more complex one does not alter the number of phases present nor does it change the phase areas previously discussed.

Considering again the two-phase area of the iron-carbon diagram, Fig. 1, that is of practical importance: application of the phase rule, equation (10) yields $A = 5$ and $B = 2$; therefore, $V = 5$, so that there are five independent variables and three dependent variables needed to describe this complex-gas-steel system. The independent variables are usually chosen as the temperature, pressure, the C:Fe ratio in the austenite, the percent H_2 and the per cent CO.** This leaves the value of CO_2, CH_4 and H_2O as dependent variables.

Within this complex gas atmosphere it is quite likely that all nine of the possible reactions listed in Table I can occur.

There are four independent equilibrium gas ratios and five dependent combinations, each of which must be established and maintained in the furnace if the carbon potential is to be controlled. The mutual interactions of the various gaseous constituents is complicated: there are five reactions in which CO_2 takes part (either as a reactant or as a product) and if any one of these five reactions can be considered to generate it independently, its presence would upset the equilibrium ratios of the other four reactions according to the LeChatelier-Braun principle. Since each of the nine possible reactions influences one or

* The ferrite-cementite-gas phase.

† When austenite and another solid phase coexist (in equilibrium), and the carbon content of one is established, that of the other is also fixed. At constant temperature, increasing or decreasing the amount of carbon in such a system merely increases or decreases the amount of the second phase present.

** Reactions (2), (6) and (8) indicate individually that either the percentage of CO or that of CO_2 (but not both) may be selected as an independent variable.

TABLE I—*Equilibrium Constants and Gas Ratios*

Reaction Number	Equation	Equilibrium Constant	Equilibrium Gas Ratios	Remarks
1	$Fe + H_2O \rightleftarrows FeO + H_2$	$K_1 = \frac{P_{H_2}}{P_{H_2O}}$	$R_1 = \frac{P_{H_2}}{P_{H_2O}}$	(Note 4)
2	$Fe + CO_2 \rightleftarrows FeO + CO$	$K_2 = \frac{P_{CO}}{P_{CO_2}}$	$R_2 = \frac{P_{CO}}{P_{CO_2}}$	(Note 4)
3	$CO + H_2O \rightleftarrows CO_2 + H_2$	$K_3 = \frac{P_{CO_2}P_{H_2}}{P_{CO}P_{H_2O}} = \frac{K_1}{K_2}$	$K_3 = \frac{R_1}{R_2}$	(Note 1)
4	$CH_4 + CO_2 \rightleftarrows 2H_2 + 2CO$	$K_4 = \frac{(P_{CO})^2(P_{H_2})^2}{P_{CO_2}P_{CH_4}}$	$R_3 = \frac{(P_{CO})^2}{P_{CO_2}}, R_4 = \frac{(P_{H_2})^2}{P_{CH_4}}$	
5	$Fe + CO + H_2 \rightleftarrows (Fe, C) + H_2O$	$K_5 = A_c\frac{P_{H_2O}}{P_{H_2}P_{CO}}$	$K_5 = \frac{A_C}{R_1P_{CO}}$	
6	$2CO + Fe \rightleftarrows (Fe, C) + CO_2$	$K_6 = A_c\frac{P_{CO_2}}{(P_{CO})^2}$	$K_6 = \frac{A_C}{R_3}$	(Note 2)
7	$Fe + CH_4 \rightleftarrows (Fe, C) + 2H_2$	$K_7 = A_c\frac{(P_{H_2})^2}{P_{CH_4}}$	$K_7 = A_cR_4$	(Note 3)
8	$2CO + O_2 \rightleftarrows 2CO_2$	$K_8 = \frac{(P_{CO_2})^2}{(P_{CO})^2P_{O_2}}$	$\frac{1}{K_8} = (R_2)^2P_{O_2}$	
9	$CO + 3H_2 \rightleftarrows CH_4 + H_2O$	$K_9 = \frac{P_{CH_4}P_{H_2O}}{P_{CO}(P_{H_2})^3}$	$\frac{1}{K_9} = R_1R_4P_{CO}$	

NOTES

1. $\text{Log } K_3 = \frac{3287}{T} - 1.650$, (T = ° Fahrenheit + 460) (17)
2. $\text{Log } K_6 = \frac{15970}{T} - 9.060$, (T = ° Fahrenheit + 460) (17)
3. $\text{Log } K_7 = \frac{8370}{T} + 5.770$, (T = ° Fahrenheit + 460) (21)
4. When F_e and F_eO are each in the solid state, the equilibrium constant is equal to the equilibrium ratio.

TABLE II

System	Independent Variables	Dependent Variables
Austenite-gas	Temperature, pressure, per cent C in austenite, CO and H_2.	CO_2, CH_4, H_2O
Austenite-cementite-gas and austenite-ferrite-gas	Temperature, pressure, CO and H_2	Per cent C in austenite, CO_2, H_2O and CH_4

more of the other concurrent reactions, the effect of one reaction alone cannot be isolated and changing the ratio of reactants to products in the case of one reaction may affect several other reactions. In summation, then: the two-phase system with a practical atmosphere is complicated by the number of variables that must be controlled if the desired results are to be obtained.

For the three-phase system (austenite-cementite-gas) with the complex gas the situation is likewise complicated. Application of the phase rule, equation (10), to this system leads to the conclusion that four of the variables are independent and a like number are dependent.* Referring again to the iron-carbon diagram, Fig. 1: only the temperature and pressure determine the C: Fe ratio in the austenite; the carbon content of the other solid phase (cementite) is constant. This means, then, that the C: Fe ratio in the austenite is a dependent variable just as it was in the case of the three-phase-simple-gas system. The phase rule allows four independent variables for this system; they are: temperature, pressure, CO and H_2 percentages. Hence the dependent variables must be the percentages of CO_2, H_2O, CH_4 and the ratio of C: Fe in austenite. Similarly, for the other three-phase system of practical interest (the ferrite-austenite-gas system) the four independent variables are: temperature, pressure and the percentages of CO and H_2, the dependent variables being the C: Fe ratio, and the percentages of CO_2, H_2O, and CH_4.

The analyses of the other complex-gas-steel systems are not dealt with in this paper for, as was stated previously, they are of limited practical importance.

It might be well to summarize the lessons learned from the application of the phase rule to practical gas-steel-systems:

a. In the austenite-gas area of the iron-carbon diagram, there are five independent variables that must be governed if the steel-gas system is to remain under control. These variables may be—(1) temperature, (2) pressure, (3) the C: Fe ratio in the austenite, (4) H_2, and (5) CO. There are. then, three dependent variables: (1) CO_2, (2) CH_4, and (3) H_2O. For every steel composition that falls within this area on the iron-carbon diagram there is an equilibrium mixture of gases such that at the appropriate temperature the steel will neither be carburized nor decarburized (nor oxidized). In other words, it is theoretically possible to match the carbon potential of a furnace atmosphere to the carbon content of any steel falling within the austenite-gas area of the iron-carbon diagram. The control of the carbon potential of these atmospheres involves the maintenance of equilibrium conditions.

b. In the three-phase regions of the iron-carbon diagram, equilibrium gas mixtures can be found that will neither carburize, decarburize, nor oxidize the steel. However, these equilibrium gas mixtures are independent of the steel compositions. If a steel is treated in a non-equilibrium gas mixture (temperature and pressure only determine the equilibrium gas composition) the steel will either be carburized (to pure cementite), or decarburized (until its carbon content decreases to the value where the A_{cm} line and appropriate temperature ordinate intersect), depending on whether the carbon potential of the gas mixture is greater or less than that of an equilibrium mixture. In the three-phase regions there are four independent and four dependent variables that must be controlled. The independent variables may be: (1) temperature, (2) pressure, (3) CO, and (4) H_2; and the dependent quantities are (1) CO_2, (2) H_2O, (3) CH_4, and (4) the ratio of C: Fe in austenite.

* $V = A - B + 2$, where $A = 5$, $B = 3$; and $V = 4$.

THE CONTROL OF FURNACE ATMOSPHERES

From a practical viewpoint, the close control of each of the gaseous constituents in an atmosphere is not economically feasible. If the carbon potential of an atmosphere is to be maintained within close tolerances, positive control of all the independent variables (with equipment that is neither expensive nor bulky and that can be used by the average furnace operator) would be ideal. By applying the theory developed in the preceding section, it can be shown that elaborate and expensive equipment is not required for the precision control of the carbon potential in furnace atmospheres.

Commercial Atmospheres

For the heat treating operations discussed in this paper an endothermic gas generator is commonly used. The output of such a generator may be enriched with natural gas (largely methane), propane or butane if it is desired to increase the carbon potential of the atmosphere for carburizing.

The endothermic gas generator consists of: air-gas metering equipment, a catalyst filled reaction retort or cracking chamber, and a cooler. In essence, the operation of the generator proceeds as follows: the metering equipment forces an air-gas mixture of the proper proportion into the heated retort where the mixture is cracked to form a gas mixture containing no CO_2 nor excess CH_4. To prevent the hot gas (which contains CO) from reacting to form CO_2 and carbon, the cracked mixture is cooled rapidly to 600° F. The theory of gas atmospheres and the details of their generation and control have been covered in several recent papers (8, 9, 10, 11, 12, 15 and 16).

A graph of the output of an endothermic atmosphere generator is shown in Fig. 2. Changes in the air-gas ratio fed into the generator alter the dew point, or water content, of the atmosphere far more than they affect the quantities of the other constituents. An average composition of endothermic gas would be:

CO: 20 per cent
H_2: 40 per cent
N_2: Balance.

The change in both H_2 and CO concentrations is very gradual (or, changes in the air-gas ratio produce

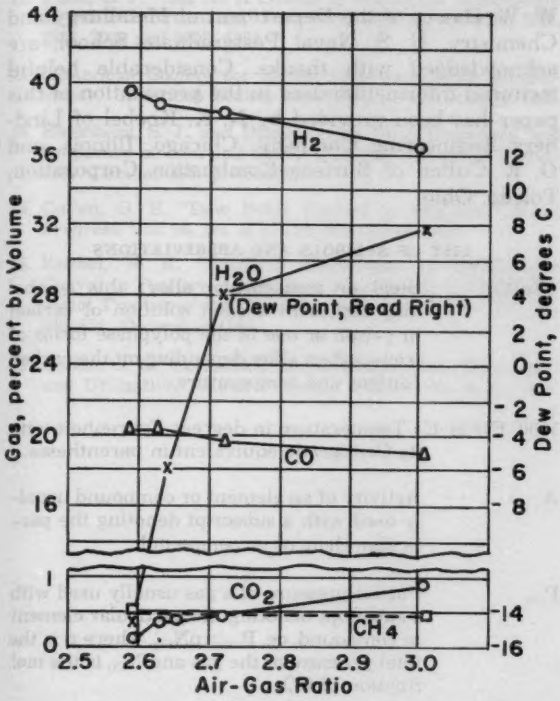

Figure 2. Analysis of Product Atmosphere vs. Changes in Input Air: Gas Ratio for Endothermic Gas Generator. (11).

much smaller changes in both the H_2 and CO contents).

Thermodynamic Basis for the Control of Atmospheres

At this point it is well to summarize the predictions of the phase rule as to the independent and dependent variables for each of the areas of the iron carbon diagram discussed in the introduction (See Table II).

The relationships between the independent variables CO and H_2 and their corresponding dependent variables CO_2 and H_2O, respectively, are given by the pertinent equilibrium constants or equilibrium ratios (see Table I).

Since K_1 and R_1, are each determined by the temperature and pressure, fixing the value of P_{H_2} (by means of the control over the air-gas ratio) establishes the value of P_{H_2O} (which would be measured as dew point). Likewise, with the value of R_2 established by the temperature and pressure, and the percentage of CO established by the air-gas ratio selected, the value of P_{CO_2} is predetermined. Furthermore, reaction (3) has an equilibrium constant that is a function of R_1 and R_2 (showing that the H_2:H_2O ratio is related to the CO:CO_2 ratio by the relation

$$\frac{P_{H_2}}{P_{H_2O}} = K_3 \frac{P_{CO}}{P_{CO_2}}$$

Therefore, the dew point is a simple and suitable measure of the H_2:H_2O ratio as well as of the

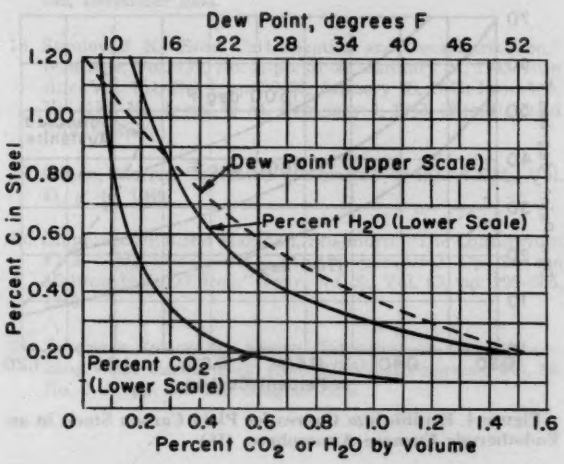
Dew Point, degrees F
Percent C in Steel
Dew Point (Upper Scale)
Percent H2O (Lower Scale)
Percent CO2 (Lower Scale)
Percent CO2 or H2O by Volume

Figure 3. Relation Between the Carbon Potential of an Endothermic Gas (20% CO, 40% H_2 and 40% N_2) at 1700° F and the H_2O or CO_2 Content. Note that the dew point curve a small error in the determination of the dew point does not a small error in the determination of the dew point does not lead to as large a variation in the carbon potential as does a similar error in the amount of CO_2. (15)

CO:CO_2 ratio. And the dew point can be readily changed by altering the air-gas ratio of the generator. See also Fig. 3.

Here, then, is the basis for the control of the heat treating atmosphere when it is in equilibrium with the steel being treated. The phase rule tells us how many variables must be controlled (as independent variables) and which ones are determined by the fixing of these (i.e., which ones are dependent). The relations between the particular pairs of variables and equilibrium ratios are established by applying the principles of heterogenous equilibrium. Coupled with these is the ability to generate a controllable gas composed of predictable amounts of CO, H_2 and N_2. Thus, a means for controlling the carbon potential of a gaseous heat treating atmosphere has been demonstrated.

The control thus exercised via the dew point measurement and the air-gas ratio is applicable to a multicomponent gas. From a study of the interrelations of the equilibrium constants and ratios (shown in Table I and Figures 2 and 3) it can be seen that

> each value of H_2O per cent (or the dew point of the gas) may represent the value of the other dependent variables (CO_2 per cent and CH_4 per cent) at equilibrium ..... (7)

Control Equipment

Since most of the heat treating atmospheres are generated and used at a pressure slightly in excess of one atmosphere, no control of the pressure is needed. There are a wide range of temperature controlling devices, some recording, others indicating, and all capable of controlling furnace temperatures to within plus or minus two or three degrees. Dewpoint measuring instruments of suitable accuracy are available for this type of work and cost from a

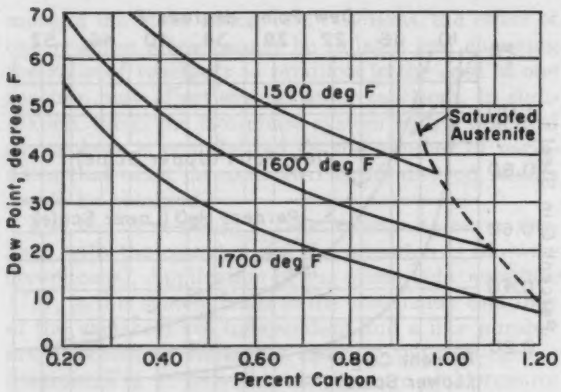

Figure 4. Equilibrium Curves for Plain Carbon Steels in an Endothermic Furnace Atmosphere. (16)

few hundred dollars on up—depending upon the complexity of the instrument; automatic continuously recording instruments are, of course, more expensive than simple indicating instruments. As for the proportioning valves on the gas generator, these may be manual or automatic and are of standard types.

Carbon Potential Control in Practice

In Figure 4 are shown a series of equilibrium curves for some commonly used heat treating temperatures. These curves are the result of a series of practical tests. These have wide applications; and, they are sometimes subject to misinterpretation. The curves of Fig. 4 represent equilibrium conditions—and they cannot be applied to other than equilibrium situations.

Remarks concerning the composition of gaseous atmospheres apply only to the atmospheres inside the furnace. The measurement of dew points must be made in the furnace (or in gases withdrawn from the furnace under isothermal conditions) and not at the generator.

CONCLUSION

In the last few years there has been an increasing industrial use of such equilibrium processes as "skin recovery" carburizing or carbon restoration, neutral hardening and controlled carburizing. Theoretically the complex equilibria found in a multicomponent gas atmosphere can be correlated and controlled through the application of the principles of heterogenous equilibria. In practice it has found that the carbon potential of a complex-equilibrium-gas atmosphere (based on an endothermic carrier gas of constant percentages of CO and H_2) can be controlled by using its dew point as the control mechanism.

ACKNOWLEDGEMENT

During the preparation of this paper the advice and helpful discussions of Professors J. R. Clark and W. W. Hawes of the Department of Metallurgy and Chemistry, U. S. Naval Postgraduate School, are acknowledged with thanks. Considerable helpful technical information used in the preparation of this paper has been provided by N. K. Koebel of Lindberg Engineering Company, Chicago, Illinois, and O. E. Cullen of Surface Combustion Corporation, Toledo, Ohio.

LIST OF SYMBOLS AND ABBREVIATIONS

(Fe, C)	Steel or iron-carbon alloy; this symbol may represent a solid solution of carbon in γ-iron or one of the polyphase forms of iron-carbon alloy depending on the carbon content and temperature.
1500°F (816°C)	Temperature in degrees Fahrenheit with its Centigrade equivalent in parentheses.
A_c	Activity of an element or compound usually used with a subscript denoting the particular element or compound.
P_{CO}	Partial pressure of a gas usually used with a subscript denoting the particular element or compound. eg. $P_{CO}=pN_{CO}$, where p is the total pressure of the gas and N_{CO} is the mol fraction of CO.
K	Equilibrium constant.
R	An equilibrium ratio of gases.

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Extremely low-temperature metallurgical research is being conducted in an attempt to unlock some of the secrets of metal behavior. It is hoped that the results of such research will lead to the ability to rationally alloy metals in order to produce desired properties. Unusual changes in properties occur at the low temperatures used, such as, poor electrical conductors at room temperature may become super-conductors at very low temperatures; poor thermal conductors at room temperature, like quartz, become excellent conductors at low temperatures. Some metals which show no magnetic properties at ordinary temperatures become forceful magnets at low temperatures.

"MECHANICAL ENGINEERING"

INDUSTRIAL ENGINEERING

ACKNOWLEDGEMENT

This article, by D. G. Malcolm, Director of Operations Research, Booz, Allen and Hamilton, was published in the December 1956 edition of "Mechanical Engineering." It is a condensed version of an article appearing in "The Journal of Industrial Engineering," November-December, 1956.

THE GROWTH of the industrial-engineering profession during the period 1940 to 1950 was truly phenomenal, as is evidenced by United States Census Bureau figures. During this period the over-all engineering profession experienced a growth of 51 per cent in individuals reporting some branch of engineering as their occupation specialty. During this same period the number of individuals listing industrial engineering increased at 7½ times this rate or a figure of 376 per cent—the total number of industrial engineers being 46,700.

There are undoubtedly several reasons why these figures should be suspect. The problem of categorizing, for census purposes, a lot of individuals who became specialists in management problems during the war years, probably forced many nonengineering individuals into this category. This fact also has had a lot to do with the breadth of the functions ascribed to the profession and the general vagueness in its definition. Many of these individuals undoubtedly would not be considered professional industrial engineers today. It is interesting to note, however, that if the census figures are discounted by as much as 50 per cent the growth was still in excess of that of chemical engineering, the next leading branch of engineering in growth during the period.

This growth has been rather uncoordinated, generally neglected, and undirected philosophically by academic engineering groups in our universities. The growth also lacked a professional society which could spell out the engineering objectives of the profession and the problem areas wherein development could and should be concentrated. As a result of such factors operating, or rather not operating, we find that the definition of industrial engineering varies considerably—depending mostly on the experience of the person with whom one is talking.

It has been characteristic of the engineering profession in America to develop along the lines of problems currently needing solution in our economy and society. Thus in retrospect, it seems quite natural that when problems of organization and management in industry require systematic study by what is referred to as the "engineering approach," the resulting knowledge and material should be grouped in this rather vague area referred to as "industrial engineering." The development during the war years was not characterized by the development of analytic tools but rather by the development of descriptive technique that literally caused the problems to disappear by shedding the light of systematic fact upon the problems then under study. The techniques developed were and are adequate for these purposes.

However, during this same period, other engineering disciplines had undergone a fundamental and pervasive shift from emphasis on the practical and experimental approaches, the *art of engineering*, to the use of mathematical methods of analysis, refined through the cooperative work of scientists, mathematicians, and engineers. As a result, the *science of engineering* as an era evolved. Thus the present-day engineering function is characterized by the development and use of a considerable "research" function which develops new analytical approaches and probes into the basic structures of our physical

world. This same sort of approach is beginning to pervade the industrial-engineering profession, offering opportunities to develop in an accelerated manner along similar analytic and research lines.

AN ENGINEERING DEFINITION

We can now make an *engineering* definition of the industrial-engineering profession. A major purpose in such a definition is to provide a means of permitting the orderly growth of a body of design knowledge for engineering functions normally considered within the sphere of industrial engineering. In this vein, I would like to offer such a definition, mindful of the fact that definitions have a dynamic quality, since the semantics of today probably will not be sufficient for tomorrow, and that the definition of engineering itself is a changing factor:

Industrial engineering is that branch of engineering concerned with the *continuing analysis* of the dynamic relationships between men, materials, machines, methods, and information, and the *synthesis* of these elements into the design of organizations, the work situation, and various types of controlling systems for the purpose of enabling the achievement of some desired ethical objective (generally at the least cost of company money and worker effort expended, and providing the maximum satisfaction of all parties involved). The industrial engineer is charged with the responsibility for the installation and the successful performance of these human systems and for providing adequate predictions of their performance and cost.*

The same words that have been used in the definition are used in block form to show the "process of industrial engineering," as it may be termed. Box 1, Fig. 1, marked "analysis," indicates that the job of analysis is to consider the various combinations of relations between men, machines, materials, methods, and information either in respect to time or with regard to distance, environment, satisfaction or the energy involved, or in respect to all of these values. This is done by one of many, sometimes alternative, analytical techniques in order to get the facts of the relationship and to provide a basis for the synthesis of the facts, or elements, into a design for an organization or controlling system or the work situation.

Then the industrial engineer should be able to predict the cost and the performance of these designs under varying conditions and to give some statement of the probable error of his prediction. Upon comparison of alternative suggestions, a recommendation is made to management for review and either acceptance or a suggestion of modification or a new analysis.

In any situation, at some time there will be forthcoming an approved design, at which time the industrial engineer's responsibility will be to make or assist in an installation of this design. The installation is generally quite a time-consuming job and, as evidenced by much of the literature of industrial engineering, there is a continual job of what might be termed "fire fighting," in order to make sure that the installation sticks and is satisfactory. Box 9 indicates that the industrial engineer is responsible for the performance and maintenance of this system (not its operation, however) and may be responsible for periodic reports of all types that may be used by management.

The loop back has been drawn to indicate that all of this should be a continuing process. That is, these particular systems or methods should be looked into continuously from the point of view that experience gained in performance and experience gained from research into the newer techniques of analysis will provide for the development of *different* system syntheses. Some of the problem areas caused by trends in business such as automation, emphasis on development, and our rapidly expanding technology are best indicated by a look at this return loop and reflecting that the industrial engineer has often lost sight of the fact that he is dealing with a continuing or dynamic process. He has quite often arrived at a design of a system, installed it, and in effect has failed to consider this return loop. Too often he merely monitors the methods and produces the reports. In many cases, industrial engineering operates almost entirely within box 9 and often without real consideration of boxes 2, 3, 4, 6, and 10.

ANALYTIC TECHNIQUES

A second problem area concerns the analytic techniques that are being used and, more importantly, the research activities that produce the *new* techniques about which we are hearing. It should be mentioned that the functions marked "research" and "development" refer to the research and development supporting industrial engineering methodology and not to the research and development on the product of the company.

Some of the various techniques of analysis of box 2 that have been used by industrial engineers are, very roughly, in the order of their development and application: process charts, motion study, flow diagrams, surveys, work measurement, fatigue studies, cost analysis, engineering economy studies, mathematical methods, statistical analysis, programming, stochastic processes, servo theory, communication-information theory, system simulation, and factor analysis.

Toward the end of the list will be noted a whole host of new techniques, or analytical methods, that

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* Members of the Cornell Symposium on Industrial Engineering developed the following definition which has been officially endorsed by the American Institute of Industrial Engineers at its annual convention, May 19, 1956:

Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of men, materials, and equipment—drawing upon specialized knowledge and skill in the mathematical, physical, and social sciences, together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems.

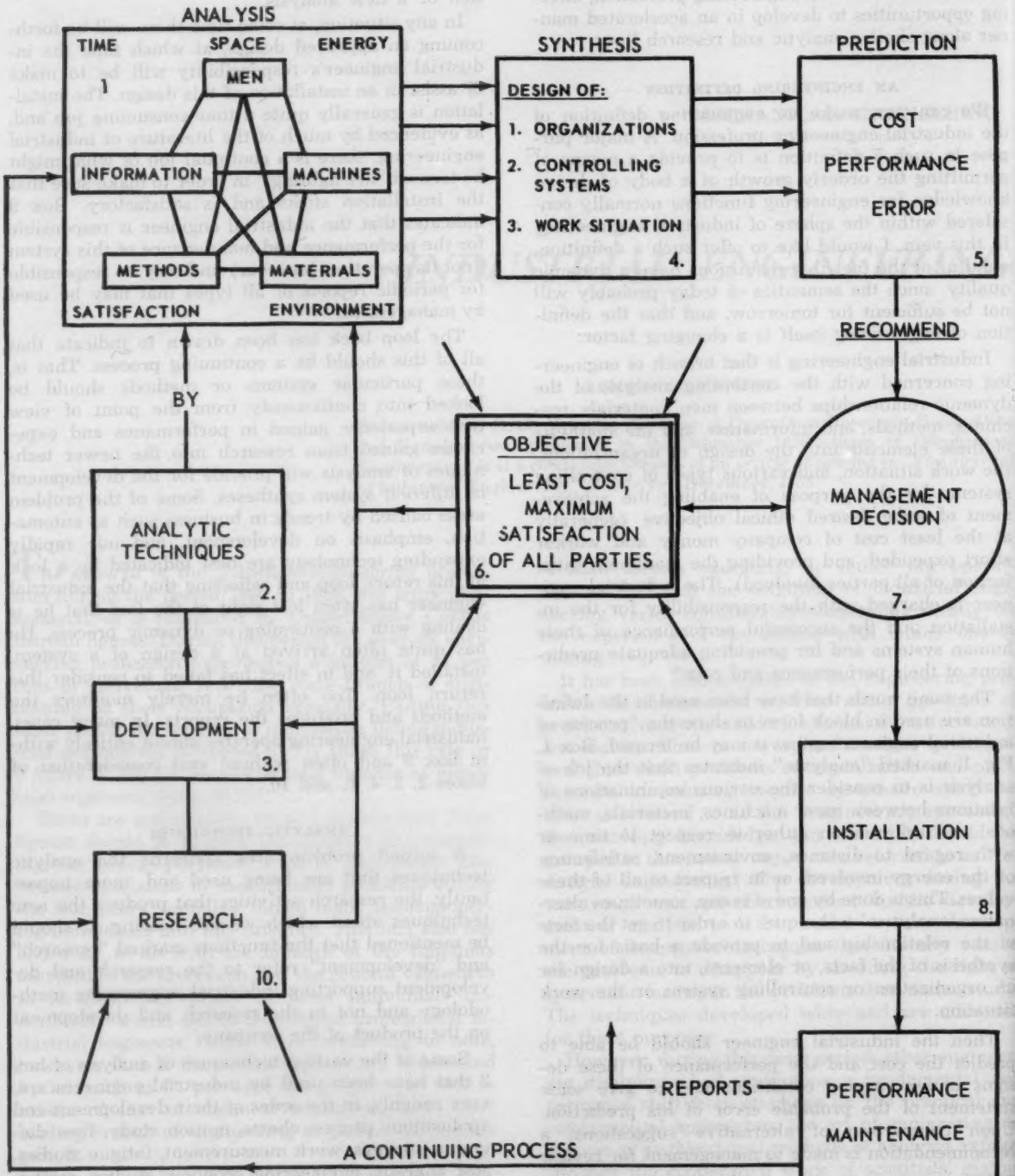

Figure 1. The industrial-engineering process—a continuing analysis of the dynamic relationship between men, machines, materials, methods, and information for synthesis into the design of organizations controlling systems or the work situation which meet the dual objective of providing a least-cost solution and also the maximum satisfaction of all parties involved.

are looming up over the horizon. How do these fit into the new industrial engineering?

First, it is important to recognize that such techniques are being developed by other than industrial engineers as well as by industrial engineers. Some of the techniques are merely in the research stage and are requiring considerable development in the way of specified procedures by the industrial engineer in order for successful applications to be made.

Second, the distinguishing characteristics of these new methods of analysis are (refer to box 1):

1. Some of the newer techniques permit inclusion of more variables in the analysis that may be important in the design. Most present techniques consider only two or three variables; e.g., men and machines with respect to time or space.

2. More of the variables may be considered simultaneously and in a dynamic method that permits a better insight into their interaction. Many of the techniques are essentially competitive and are often alternative tools for solving the same problem.

3. As a result of making analogs of the real system —either mathematical models or computer models— evaluation of different designs for control systems can be made. Thus we can look forward to a *theory* of inventory control, a *theory* of production control, and the like.

The impact of this development will be considerable but not as revolutionary as some would have us believe. While many of the present industrial-engineering techniques are essentially descriptive and the over-all effect of the industrial-engineering approach is sometimes experimental, the good judgment and experience of the business system have been sufficient and adequate to come up with decisions that are probably quite satisfactory and will probably continue to be. However, many of the questions in regard to, say, inventory control, concerning optimum reorder points and quantities and the optimum inventory size considering production efficiency and all distribution costs have been answered by experience rather than by analysis.

Competing techniques of system simulation and servo theory are offering the possibility of analyzing such systems in a dynamic context and permit analytic determination of many policies and procedures, thereby providing a basis for the development of optimum sets of rules.

The technique of system simulation (sometimes called the Monte Carlo method) and stochastic processes are permitting analysis of interference problems and balancing and peaking problems. Where we have formerly considered only the average time, it is becoming possible to allow (in the analysis) for the variable nature on many of the elements in a production line.

SYNTHESIS AND DESIGN—THE UNIVERSITY'S ROLE

The results of the analysis, whatever type it may be, lead to the process of synthesis, box 4. Thus industrial engineers design organizations, controlling systems, and the work situation. Typical examples in each design area are: (1) Organization—procedures, structure, policies, and measures of effectiveness; (2) Control Systems—quality control, production control, inventory control, and cost and budgetary control (labor, support staffs, and organization); and (3) Work Situation—materials handling, plant layout, work methods, wage determinations, and maintenance.

There has been a tendency in industrial-engineering academic research to overconcentrate on the detailed analysis of the work methods. While these are necessary lines of investigation, a lack of scientific attention to the over-all work pattern has resulted. Simply stated, there has not been nearly enough attention paid to the more powerful analytic tools for system analysis.

However, at this time, a survey of our universities indicates a real drive and effort to move in this latter direction. Many of our colleges now have the goal of training engineers to be in a position to introduce change in about 15 years—not merely to be able to keep up with it. Fifteen years is chosen because this represents approximately the time before the engineer is able to make the most effective contribution to his company. Courses in linear programming, probability theory, information theory, servomechanisms, operations research, etc., are appearing at an increasing rate. As greater experience is gained by faculty members, there will be a shifting of emphasis in the appropriate undergraduate technical courses for the industrial engineer. The basic mathematics of the industrial engineer differs from that most useful in other engineering branches.

Thus industrial-engineering managers should begin to have a wider range of training from which to select new employees, and are already finding it necessary to modify their organizational structure in order most effectively to use these talents. It may well turn out that graduate engineers from other engineering branches, research groups, etc., will be more satisfactory employees for the industrial-engineering department before this educational process is fully established.

To summarize, it is evolving that the greatest payoff in the coming decade will probably come from increased attention in this systems area. A theory of organization seems to depend first upon satisfactory solution to the problems of control. We can look forward to communication-information theory to be very useful in getting at the problem of optimum communication flow. As one enthusiastic writer* indicates, "The particular strength of the communication theory lies in its ability to describe in the precise language of mathematics the statistical performance of all components, human or mechanical, of the industrial engineer's realm."

* "The Industrial Engineering Application of Communication-Information Theory," by A. B. Rosenstein, *The Journal of Industrial Engineering*, vol. VI, no. 5, September-October, 1955.

PREDICTION OF COST PERFORMANCE AND PROBABLE ERROR

The methods for prediction of cost performance and probable errors in these estimates are requiring more attention. In order that the right decisions will be made and installations of new systems may be effected in the least time, more frequent, elaborate, and accurate predictions will be required. These will require consideration of the likely trends in labor relations, the increasing number of technological choices available, the likely need for increased frequency of change in basic processes and methods, and an increased knowledge of what a competitor is doing in *his* process. The techniques of time-series analysis, time-reduction curves, and mathematical programming will receive increasing attention.

MANAGEMENT DECISION AND THE OBJECTIVES OF THE ENTERPRISE

Management is entering the picture in more than one way, as evidenced by boxes 6 and 7. Management is continually looking at this heart of the system—box 6. What are the over-all objectives and policies that will permit the most satisfactory growth or profit of the entire enterprise? Management has the job of fitting together many other functions, of which industrial engineering is only one, into a best over-all solution.

While this "heart" is being worked on from many factors from the outside, we can say that modern management is quite aware of the need for expression of human values to be included in systems design and at the same time is mindful of the need to produce the best possible product at the least cost of money and worker effort. As a result of this philosophy, management is asking questions concerning the adequacy of the methods of analysis employed. This is causing a greater emphasis on research and development of techniques for better, more timely, and comprehensive analysis.

The new industrial-engineering function that is emerging is being characterized by this gearing of management thinking to box 10. More and more industrial-engineering functions are building-in a research function. This will permit understanding and application of the newer methods of analysis at an earlier date and should have the return of permitting a broadening of the objectives of the entire enterprise. This in turn is an important competitive tool in today's manpower shortage.

INSTALLATION THEORY

The industrial engineer is generally responsible for the installation of his designs. The length of this installation phase and the frequency of introducing change are subjects of increasing importance.

It is generally desirable to install a system, etc., with the minimum of confusion, so that the learning effect (time-reduction curves in the aircraft industry) is minimized. Also, with the general desire on management's part to be able to introduce new models, or products, at an increasing frequency, it becomes necessary to select the analytic technique (where different tools are available) that minimizes the total cost of the production.

So it should be evident that there are gains, by way of reduced cost and competitive advantage, to the enterprise that is able most successfully to cope with this "installation phase." It therefore becomes quite important for more systematic knowledge to be brought to bear on how long it takes for a control system, an organization, etc., to respond to the new desired way of doing things. To reduce the installation time requires a feedback to research and development and should be the subject of considerable exploration by the industrial engineer.

With everyone else coming up with a "theory of this," or a "theory of that," perhaps this offers the industrial engineer a chance to coin a theory also—perhaps this area of study of the installation schedule and procedure should be referred to as "installation theory," with its objective the "study of the most over-all efficient way of introducing a change."

PERFORMANCE AND MAINTENANCE

In many companies the responsibility for the performance of others in regard to a given design is the ultimate responsibility of the industrial engineer. If they or the system can't do what he says is possible, it becomes the industrial engineer's job to determine the source of the trouble. If his design is at fault, he has a redesign job to do; if line management, supervision, or interpretation is the source of the trouble, the industrial engineer must insist on correct procedure.

There is a trend in the industrial-engineering function to get out of the data-processing area. Thus reports issued by industrial-engineering departments are now more of the nature of interpretive reports of other organizational functions whose systems the industrial-engineering function is responsible for designing.

The industrial-engineering department conceived as an internal consulting function may well become an organizational precept and indeed is the central theme of the new industrial engineering.

COMMANDER BERNARD M. KASSELL, USN

MARINE ENGINEERING NOTES FROM THE SOVIET PRESS

THE AUTHOR

enlisted in the Navy in 1931, and has served continuously since that time. He attended Cornell University and Maryland University, obtaining his B.S. degree in Military Science from the latter institute. He has had a wide range of duty assignments, including tours as Engineer Officer and Repair Officer on various ships and tenders. This is his fourth article to appear in the JOURNAL. *He is currently stationed in Port Lyautey, Morocco.*

The materials contained in this article have been taken from Russian language publications. The translations are the work of the author.

INTRODUCTION

THERE IS MUCH to be said for Winston Churchill's "riddle in an enigma" statement of some years ago when one attempts to apply Western thinking and Western ideas to the Soviet Union. Naval engineers and naval architects, among others, when confronted with Soviet shortcomings may be prone to think that their Soviet counterparts are behind the times in their thinking. And they are right—but only partly so. As the counter to such thinking, reflect upon the *Sverdlovsk* class cruiser, the new destroyers, the vast submarine fleet. Surely it was something other than backwardness which brought this armada into being. The something, we are inclined to think, is the well-known, yet frequently overlooked, propensity of the Soviet Union to place the emphasis squarely where the planners feel it should be placed —without special interests overriding that emphasis or diverting the available resources. And resources in our fields of interest are relatively scarce. Scientists and engineers, designers and technicians, are scarce and are above the throng in the Soviet view, a commodity to be coddled and pampered and at the same time driven to produce the things which the planners have placed on the agenda at the time stipulated for each item.

Thus the items may range from small river craft to the seemingly mighty *Sverdlovsk*. And each has its place in the scheme of things. The 150-ton cargo carrier is needed to traverse the shallow rivers and bring out to deeper water the commodities that cannot reach the river ports or the railroad stations. Strategy dictates the scope of the naval building program, yet strategy stems from a careful reading of Western statements and a careful analysis of Western thinking—with a heavy emphasis placed on Soviet aims *vis a vis* the West. It is not without reason that Soviet publications reprint items from Western sources, for these reprints reflect the interests of the Soviet Union in Western ideas and developments.

Just as in the early thirties the Soviet Union drew on Western ideas and produce and in many cases took such produce for its own, today the process continues. Technical notes on many subjects are covered in Soviet trade journals and in the press. Perhaps it was no accident that Soviet interest in certain types of merchant ships, for example in pre-war days, led to the demand as reparations of just such types after the war was over. Today the emphasis continues as editors reprint what may be on the order books in the near future. "Soviet Notes" will attempt to reflect these changing ideas and attempt to bring into focus current Soviet thinking in the fields of naval engineering, as well as the actual results of such thinking in the field of operations.

When we read of plans for an atomic icebreaker we dare not write off the possibility of realization as a crackpot's dream. At the same time we cannot

credit Soviet builders and scientists as fully capable of a task as complex as this until we see the actual vessel. Our signs in the wind frequently are forerunners of shocks to our thinking, as witness the first A-bomb explosion, the first new tanker, and the TU-104 jet transport. Hence we must continue to make day-to-day evaluations and reevaluations of Soviet potentials and capabilities, changing our conclusions as we add to the complex equations new, and all too variable, factors.

MAIN PROPULSION FOR TANKERS

Some of the details as to the number of tankers presently active in the Soviet merchant fleet, as well as some of the difficulties encountered in the main propulsion for these tankers, have recently been revealed in the Soviet press.

We learn, first of all, that at least twelve tankers of the *Kazbek* class have, in the past two operating years, because of engine difficulties, been able to operate but 14 months, on an average per ship. The *Kazbek* class (or, as it is sometimes referred to after the second vessel in the series, the *Leningrad* class) is the Soviet post-war tanker, as well as the first major merchant ship building program to be undertaken in the Soviet Union since the 1930's.

Since certain of the characteristics of the class have been made available, and because the class is relatively small as compared with Western tankers, it is considered worthwhile to look into the program as a whole before taking up the engines themselves.

The *Kazbek* class is a single-screw, single-deck tanker designed to transport petroleum and petroleum products. (Singularly enough however, the first reports of tanker use for the transportation of dry cargoes came from the Soviet press when it was announced that tankers returning from Communist China were carrying cargoes of soy beans.) Some of the type characteristics follow:

Length	145.5 meters
Length between perpendiculars	138.0 meters
Beam	19.2 meters
Height of side	10.4 meters
Draft, light	0.98 meters, forward
	5.15 meters, aft
Draft, full load (mean)	8.50 meters
Gross Registered Tons (estimated)	8,000
Cargo Carrying Capacity	10,000 metric tons
Speed (trials)	13.3 knots
Range, nautical miles	10,000
Crew (including 12 cadets)	56
Classification, USSR Maritime Register	LR 4/1 S (Petroleum)

The hull, which is all-welded, is a combination of the longitudinal-transverse system. The sides, platforms, and longitudinal bulkheads use the transverse system of framing. The decks and bottom-plating are of the longitudinal system, except in the double-bottoms area, the stern section in the engine room area, and the bow section forward to the peak tank, where the bottom-plating is transverse. The hull is reinforced for use in the ice encountered in northern waters, suggesting possible utilization in areas such as the Northern Sea Route. Configuration is standard, with stack aft, over the engine space.

Carbon steel (Mark ST-4S) has been used for hull plating up to 15 mm in thickness, while a low-alloy steel (Mark SKhL-1) has been used for 15mm and thicker plate. The hull itself consists of 16 transverse bulkheads and two longitudinal bulkheads. These bulkheads divide the hull into 33 basic watertight compartments (less the double bottoms) which make up the 24 cargo tanks and two cofferdams, as well as the compartments for machinery, etc.

Auxiliary machinery, in contradistinction to main propulsion, includes two four-cylinder Diesel engines, Mark 4D-30/50, used to drive the ship's generators. Steam for cargo pump use, as well as for warming tanks, and other uses, is provided by two boilers, Type KVS-68/1, each capable of producing 8 tons of steam per hour. Fresh water is provided by a Type VP-3 distilling plant, with a capacity of 10 tons per day. The ground tackle consists of two 4,000 kg Hall anchors, together with one 1,500 kg kedge anchor. Chain links measure 62 mm and the vessels carry a scope of 275 meters for each anchor. The anchor windlass is electrically driven. The steering machinery is an electro-hydraulic system for the single rudder, which latter has an area of 17.5 square meters. Rudder controls are located on the bridge and on the after poop deck. Hand control is available for emergency use. It is not known whether the emergency generator installed is large enough to handle the steering load. Steam smothering, foam, and fire main systems are provided for fire protection.

The scope of the *Kazbek* class program is unknown, but shipping and press reports suggest that since the program was started, approximately six years ago, more than twenty-five such tankers have entered service. There are indications at present that the Ministry of the Maritime Fleet has under discussion plans for the construction of tankers capable of carrying 16–17,000 metric tons, but that no suitable engines are available or in production. This latter point brings us back to the engines for the *Kazbek* class.

The engine selected for main propulsion in the class is known as the 8DR-43/61 and has proven, in operation, to be unsatisfactory. The engine is an eight cylinder, directly reversible, two-cycle Diesel engine with a bore of 43 mm and a stroke of 61 mm. It was designed to develop 2000 hp at 250 rpm. The engine was designed in 1940 in the "Russkiy Diesel" Works for large merchant ships and was touted as being simple to construct and service, but more especially, was supposed to be reliable in operation.

Reports now indicate that the engine breaks down quite frequently. There have, evidently, been serious accidents on the tankers and premature wear of cylinders, pistons, liners, etc., has been encountered. The casualty tally on twelve ships in the series, in two and one-half years of operation, has been: 6 cracked blocks, 159 cylinder studs, 177 cylinder cov-

ers, 60 pistons, 23 piston caps, 1924 injector springs, etc. Replacement costs for the items enumerated have amounted to over two million rubles. In this same period, 31 complete overhauls were accomplished on the engines and, because of breakdowns and time lost in making repairs, the Black Sea Steamship Company alone reported a loss of over 50 million rubles for the period.

Personnel of one tanker in the class, *Frunzye*, quite matter of factly report that they expect to change between 100 and 200 injector springs in the course of a long trip. Engineers on the ship have experimented around in an effort to overcome this difficulty and claim that shortening the lift of the injector needle adds 500 hours of operation to the normal life of the injector. This particular crew thus managed to keep spring changes down to 25 on a trip between Odessa and Vladivostok. Another experiment involved the use of one and one-half springs in the injector body. This jury rig is credited with extending injector life to somewhere between 1,000 and 1,200 hours of operation before change or repair is required.

Frunzye also reports engine room temperatures, particularly in the tropics, to be excessive and reacting adversely on both men and machinery. The installed exhaust blowers are unable to keep the temperature below the range of 113° to 122° F. Soviet seamen have found a temporary solution in reversal of the exhaust fans to provide a greater flow of air into the engine spaces, an expedient which has brought temperatures down to somewhere in the vicinity of 100° F.

Along with the mechanical failures reported, cooling jacket corrosion has been encountered on the 8DR engine, apparently the result of excessive air in the water jacket. Efforts to bleed excess air out of the system have met with some slight success on individual ships.

All these defects caused an engineer named V. Smyika to make the flat statement that the "Russkiy Diesel" Works is producing, in the 8DR, a poor quality engine, the production of which must be stopped. His point is that little good will come of remodernizing an obviously unsatisfactory engine, particularly one which is outmoded—obsolete. The 8DR, as designed, had a fuel consumption of 185 grams per effective horsepower per hour, or less, when operated on Diesel oil. Engineer Smyika claims that modern Diesels should use not more than 155 grams/ehp/hr. He cites a *Kazbek* class tanker as underway an average 7,000 hours per year. In a year a tanker of this class consumes 5,180 metric tons of Diesel fuel at a cost of 1,640,000 rubles. Smyika prefers the use of a "modern" engine, one which would use but 4,340 metric tons of fuel at a cost of 1,130,000 rubles. He notes that if cheaper fuels, such as boiler fuel, were used, the saving would be even more substantial. No mention is made of comparative operating efficiency or maintenance costs, however.

Smyika raises yet another point—that of size of installation. Two 8DR engines, together with the reduction gear to couple the engines to the single shaft, have an overall length of 13.47 meters and a width of 5.93 meters for the 16 cylinder aggregate. It is pointed out, comparatively, that the Doxford engine provides the same power as the 8DR in a package of four cylinders, with a length of but 7 meters and a width of 4 meters. This reduction in size of unit yields additional cargo space of some 700–800 cubic meters, as well as making the arrangement of machinery in the engine room a simpler matter.

For the future one may expect continuing objections to the program of modernizing an obsolete engine, with voices raised in favor of producing a modern, economical engine suitable for tankers larger than the present *Kazbek* class. This surmise leads one to conjecture whether "Russkiy Diesel" will do the development work, as the past history of the Works suggests is the case.

This engine-building plant, located in Leningrad, goes back to pre-Revolutionary days in Russia when it was the Nobel Engine Building Works. Commencing in 1892 the Works produced a four-cycle engine, but, at the turn of the century shifted over to the production of two-cycle, kerosene burning engines. By 1902 experiments were underway with compression ignition in two-cycle engines, and, by 1906 the first such engine was built, rated at 20 hp and using crankcase scavenging. This engine, called the "S" Type, came about as the result of work done by Staff-Captain of Artillery A. Frolov, who, as a result of his invention of a special, separate supercharger for scavenging as well as a receiver for scavenging air, was given the privilege of retirement from the service, presumably with pay. This work had occurred in 1899, with the inventions being turned over to the "Russian Company for Diesel Engines" for production in 1903. Culmination of the work took place as has been noted, in 1906.

After the advent of the Soviets the "Russkiy Diesel" Works, as it was renamed, specialized in the two-cycle, compression ignition engine it had developed as a private company. Soviet needs forced the Works, beginning in 1923, to develop a number of new engines using the compression ignition system. In 1925 a one-cylinder, two-cycle, solid-injection engine came out. Designated the 2050 series, it developed 50 hp at 45 rpm and used loop scavenging. About the same time production was started on a two-cycle, 6-cylinder, reversible engine for use in the merchant ships then under construction in Soviet shipyards. This engine, the 2126 series, was a cross-head type developing 750 hp at 185 rpm. By 1927 the 2400 series engine was produced and installed in motorships being built for the Baltic and Black Sea steamship companies. This was a reversible engine, in the 1900–2200 horsepower range at 100–115 rpm. This type was later modernized by the Works in order to simplify its operation.

There followed almost complete absorption of production capacity in the manufacture of 3000 hp

engines for installation in motorships—tankers, reefers, lumber carriers and passenger types—being built for service on the Leningrad-Vladivostok, Leningrad-London, Leningrad-New York, and Leningrad-Odessa lines.

By the time this program was completed, or nearly so, the plant turned to the design and construction of a four cylinder, directly reversible engine which came to be known as the 4DR-24/28 series. Design commenced in 1934 and, by 1936–37 the engine, rated at 240 hp at 375 rpm, was placed in "serial" (mass) production. Later designs included the construction of a series of large marine engines rated at 4200 hp from nine cylinders, as well as an experimental type of two-cycle engine rated, in 1941, at 6000 hp. During the war a design for a two-cycle, double acting engine rated at 10,000 hp was worked on, but there is no evidence that the engine ever got into production. While not all the engines were for marine use, the plant has continued to work in that field, both in the design and production areas, throughout the years.

With its background of marine engine production it would be natural to suppose that the plant has contributed to the submarine building program presently underway in the Soviet Union. No definite evidence is available however, but it makes interesting speculation to suggest that priority in both design and production has been assigned to the Soviet Navy. In turn, it can be suggested that should this be the case little remains for the merchant fleet but the defective 8DR-43/61 engine, both now and for the near future.

NEW SHALLOW DRAFT TANKERS

The Caspian Sea and the rivers of the Soviet Union pose special problems for both the military and civilian consumers of petroleum and petroleum products. For example, a load of POL carried from Krasnovodsk to Stalingrad must be handled four times during the journey. First loaded in Krasnovodsk, it must be trans-loaded from the tanker in which it crossed the Caspian into barges of the Caspian Roadstead Steamship Company at the Volga delta, from whence it proceeds to Astrakhan. Here it is once again transloaded into barges or tankers belonging to the Volga Tanker Steamship Line, a river operator, and transported to its destination, where the final handling takes place.

In an effort to overcome the time lost in this operation, as well as to reduce costs, Soviet designers have created, and a Soviet shipyard has built the *Oleg Koshevoy* class tanker, some details on which have been published.

Length, overall	123.5	meters
Length, between perpendiculars	115.0	meters
Beam	16.0	meters
Height of Side	5.5	meters
Displacement, empty	1,795	metric tons
Mean draft, empty	1.3	meters
Maximum cargo carrying capacity, sea	4,000	metric tons
Mean Draft, full load, sea	4.0	meters
Maximum cargo carrying capacity, river	2,600	metric tons
Mean Draft, full load, river	3.2	meters
Self-sustaining	10	days
Fuel, water, and lube capacity	128	metric tons
Crew	44*	
Full Displacement, at sea	6,030	metric tons
Full Displacement, river	4,660	metric tons
Total Horsepower, main engines	1,600	
Speed, full load, draft 3.2 meters	10.5†	knots

* Same number as for *Kazbek* class tanker.
† This is river use, with no figures available for corresponding sea use. It is estimated that little additional speed is available.

Available information indicates that the class is under construction in one of the yards subordinate to the Ministry of the Shipbuilding Industry. Designed to eliminate the time-consuming and costly transhipment operations mentioned above, the tanker is the work of two Soviet engineers, V. A. Yevstifeyev and B. V. Bogdanov, who laid the ship down in accordance with the rules of the Maritime Register of the USSR, Class LR 4/1 S (Experimental).

The tanker is a single-deck, twin-screw, Diesel-driven vessel with stack aft and house amidships. Pump room is also amidships. The design incorporates wide use of automatic and semi-automatic welding, with construction accomplished in sections and blocks which are later fitted together to make the whole ship.

Framing in the cargo hold areas is longitudinal along the bottom, while for the decks and in the extremities it is transverse. Possible use of the vessel in waters where ice would be encountered (winter time in the Caspian, for example) resulted in the strengthening of the hull for such use in accordance with the rules of the Register for class "L" (from the Russian word for ice—"lyod."). The vessel is designed to cope with sea conditions when wave heights reach 5 meters, and the calculations which led to settling the design incorporated a wave length equal to the length of the vessel itself.

Hull steel is especially strong, Mark SKhL-1, as in the *Kazbek* class, with a yield point of 3,500-kg/cm^2. The superstructure is built of ordinary carbon-steel, Mark ST-3S, and the internal bulkheads and partitions are stamped, without framing.

The hull encloses six amidships and 12 wing cargo tanks which, together with the pump room, are located amidships in the hull. The tanks are divided into two separate groups, thus permitting the loading of two different types of cargo at the same time. As designed, the tanker is supposed to carry gasoline with a gravity of 0.74, petroleum products with gravities between 0.80 and 0.91, as well as lubes and heavy products which must be heated. Cargo pumps are electrically driven, type 10NDV, each capable of handling 500 cubic meters of water per hour at a head of 39 meters (water column measurement).

Main drive is provided by two 8DR-30/50 Diesel engines, of 800 hp each at 300 rpm. The engine shafts are rigidly connected through stub shafting to the individual propeller shafts. The deadwood bearings are rubber-metal inserts, water cooled.

Steam supply is provided by two auxiliary boilers of the water-tube type, Mark KVV1/5, each with a heating surface of 28.2 square meters and capable of generating 1000 kg/hour at 5 kg/cm² pressure. Steam is thus available for heating the cargo, steaming out tanks, and heating the ship itself. Experience on the lead tanker, however, showed that the installed boilers did not provide enough steam for proven needs.

A distilling plant, Type VKZ, with a productivity of 7 tons/day, is installed to provide needed fresh water.

Lighting and power are provided by four Diesel-generators, Type DG-75, rated at between 75 and 82 kw at 230 volts, direct current. Some lighting at 115 volts is provided from Type PN-145 converters, rated at 16.2 kw and driven by 220 volt motors.

The generators are installed in a sound-proofed compartment in the forward part of the engine room. An emergency generator, driven by a 4Ch-8.5/10 Diesel engine provides 115 volts for emergency lighting, running lights, radio and searchlights. The unit is rated at 12.5 kilowatts, alternating current is provided by two motor-generator sets, the generator rated at 5 kilowatts at 127 volts, and the motor at 7.2 kilowatts. Steering equipment is electrically driven, Model RER-22-1, servicing the single rudder, the blade area of which is 12.8 square meters. Control stations are located in the wheelhouse and on the poop deck, with hand steering available in an emergency.

The anchor windlass is an electrical installation, Type BER-6, with two standing anchors weighing 2,500 kg each on chain with 46 mm links. The stern anchor is a 1,000 kg affair on a 34 mm chain handled by an electric windlass, Model ShER-5/a. Two 5 ton winches are also provided for use in mooring.

Radio gear includes a long-wave unit, PT-2.5, and a short wave set, PSK-0.25, as well as an emergency set, ASP-3-0.06. Two all-wave receivers, type PRV, and an emergency receiver, type PAS-1, are the reception devices. For navigation there is the usual magnetic compass, a gyro compass, an electric log, fathometer, radio direction finder, and radar with stations in the wheelhouse and on the open bridge.

During her trials the *Oleg Koshevoy* proved to have good sea-keeping qualities. The trials, held in the Caspian Sea, turned up certain discrepancies which led to modifications being made in the tankers laid down in 1955. The later tankers are to have larger boilers, and are one deck lower amidships and aft. The amount of equipment on the main deck is reduced and the main engine exhaust is utilized, presumably as a heat source. The cargo and stripping systems in the cargo tanks have been changed to enable the tanks to be stripped regardless of drag or list.

Little is known about the scope of the *Oleg Koshevoy* program except that in mid-August, 1956, it was announced that a new tanker in the class, *Ivan Zemnukhov*, was in operation in the Caspian. This, together with the lead tanker and *Aleksey Kryilov* and *Sergey Tyulenin*, brought to four the number of such vessels reported as operative in the area. In addition two other tankers, *Ulyana Gromova* and *Lyubov Shevtsova*, were scheduled to arrive in the Caspian area sometime later in 1956.

Since at least one river yard is engaged in this program the weather is a strong determinant in so far as deliveries are concerned. As has been practiced in Soviet river shipyards over the years, work is carried on during the winter months, with completion dates set to coincide with the breaking up of the ice and high water as a result of melting snows and ice. Thus vessels normally are taken to sea in the spring and summer. Any delays in construction are therefore reflected in late deliveries, sometimes a year later than planned. However, from the time involved in this program, and the reported delivery dates thus far, the building rate for the four presently in service appears to be about six months per unit.

SOVIET SUPER TANKER

Late in September, 1956, the Soviet Union announced the first project for a "super" tanker. The planned tanker is to have a cargo carrying capacity of 25,000 tons, about two and one half times the capacity of previously built tankers. While not up to Western standards for a "super" tanker, the vessel should satisfy Soviet needs. In fact, it is somewhat debatable whether a larger tanker might not be more of a hindrance than a help to the oil carrying fleet. Ports and facilities probably cannot handle much larger vessels than this one; hence, as has been pointed out previously, this size fits in with the needs of the country.

When the announcement was made the tanker was only in the preliminary, or sketch, phase of development. The Soviet shipbuilding industry generally passes through three phases prior to construction. The first phase is the sketch phase, followed by a technical stage in which the details of construction, bill of material, etc., are drawn up. Then the working drawings are produced, forwarded to the building yard, and construction usually commences. Thus, we cannot expect to see the new vessel on the high seas much before 1958 or 1959.

As planned, however, the vessel is to be turbine propelled, the unit rated at 19,000 horsepower to give the ship a speed of 18.5 knots. The tanker will be 188 meters in length and will have an over-all beam of 25.8 meters. Of all-welded design, the hull will weigh some 6,000 tons and will incorporate many new and interesting features.

It may be recalled that the Soviet Union pioneered in the field of transporting bean and grain cargoes in tankers. Apparently successful, these efforts have led the designers to incorporate in the cargo holds technical features which will improve tank cleaning and will help to speed up the offloading of the dry cargoes transported. Much effort is reported to have gone into the watertight integrity of the vessel and

special efforts have been made to make the crew comfortable. Items such as single and double cabins, a beautiful messhall, and a music salon are included. From a more practical seagoing standpoint it is expected that the vessel will be fitted with the latest in radio and navigational equipment and both cargo and cleaning systems will be installed to enable the simultaneous reception and discharge of three types of cargo.

The artist's sketch which accompanied the report depicts a clean-lined vessel with a clipper bow, a house amidships, and the usual house and stack aft. No mention is made of the building yard, or the scope of the program.

NEW WHALER UNDER CONSTRUCTION

With the announcement in September, 1956 of the fact that the I. I. Nosenko Yard in Nikolayev had been assigned the task of building a new whaler, there ended some speculation as to just what was going on in Soviet shipbuilding circles. In July 1956 *Sudostroyeniya* (Shipbuilding), the organ of the Ministry of the Shipbuilding Industry, published an artist's sketch, together with some details of what was called a "whaling base" to join the *Slava* and *Aleut* as base ships for the whaling expeditions dispatched annually by the Soviet government.

As opposed to the new "super" tanker, the working drawings for the whaler have been completed and were reported in the hands of the yard force. More than usual interest in the vessel stems from the fact that here is perhaps the largest vessel yet attempted by Soviet merchant ship builders. Coming just prior to the announcement of the planned construction of the "super" tanker, this news suggests increased capabilities on the part of Soviet designers and builders, as well as available facilities in the designated shipyard.

According to the project the whaler is to be a twin-screw, triple decked vessel with a ramp in the stern through which the whale carcasses can be brought on board for processing. The cruising radius is designated as "unlimited" and the vessel is designed to receive and process whales captured by its auxiliary fleet. In addition, it will act as a storage base for its production, a supply point for its fleet and will serve as a barracks for the crews of the auxiliaries both while they are operating and while in transit. Some characteristics:

Length overall	217.8 meters
Beam overall	27.8 meters
Height of side, amidships	19.0 meters
Displacement, full	43,800 metric tons
Deadweight	26,700 metric tons
Draft, full load	10.6 meters
Speed	16 knots
Engines	2 x 7000 horsepower

The planned main propulsion installation is to consist of two slow-speed (115 rpm) Diesels of unspecified designation. This fact, of itself, is curious, particularly in view of the difficulties which the Soviet merchant fleet seems to be having with its main engines. The possibility exists that the engines may be imported. All that is known is that they will be 6-cylinder, two-cycle, reversible, single-acting, supercharged units.

Electricity will be provided by four 750 kw turbogenerators, another interesting departure, particularly in view of the fact that no mention is made of boiler installation.

The vessel will carry a crew of 510 officers and men, who will be berthed in both one and two-place cabins, all of which are to be air conditioned.

Modern steering and navigation gear will be installed and a helicopter will be provided to improve the ability of the expedition, headed by the as yet unnamed vessel, to hunt whales.

The artist's drawing shows a tanker-type hull with twin stacks (port and starboard) aft, a house forward, and another, lower house, amidships. Radar and radio masts and antennas are also depicted.

NEW STEAM ENGINE DESIGN

While Soviet marine engineers continue to work on Diesel engine designs for the merchant fleet, counterpart engineers working for the river fleet have problems with steam engine design. River vessels propelled by steam engines vary in their installations from 200 to 1,200 ihp, with models of many different designs. Many of these older installations have become uneconomical to operate and many others are simply obsolete.

Three Soviet designers, Ye. Al Tatur, N. S. Genkin, and A. P. Lebedev, working for the Moscow Central Planning and Design Bureau, recently came up with a set of plans for a new, small, marine steam engine to be used for main propulsion. The unit, in its experimental form, was designated the MP-10 and was turned over to the "Teplokhod" Works for construction and testing. After a series of tests were concluded last year the engine went into serial (mass) production in the above-mentioned Works.

The new engine is reported to differ from previously built engines in that it is more economical, has a wide range of power ratings and revolutions, and is of modern construction.

The MP-10 is designed to operate normally at a boiler pressure of 16–18 kg/cm², the steam temperature after leaving the superheater between 300° and 330° C. A pressure of 28 kg/cm² and temperatures between 360° and 380° C. can also be used. The indicated horsepower rating of the MP-10 can be varied from 200 to 450 and, at the higher pressure and temperatures, is reported as indicating 600 horsepower. Engine revolutions, depending on the steam supply, vary between 200 and 400 per minute.

The new engine can be used for main propulsion in vessels rated variously from 200 to 1,200 horsepower, the latter size based on a twin engine installation. It may be installed directly coupled to the shaft, or a reduction gear may be used if required. Additionally, its use is not restricted to transport and towing ships. The MP-10 may also be installed

in vessels of the so-called "technical" fleet (dredges, etc.) or it may be used as an auxiliary steam engine for driving electrical generators on large sea-going ships, according to the designers.

In design the engine is of vertical construction, with slide-valve steam distribution, reversible, double expansion, duplex, double acting, closed type with a system of lube oil circulation. Condensate is recovered from a surface condenser, from which air is excluded by an ejector installation. The engine can be manufactured for both left and right-hand rotation. The two blocks of cylinders each contain an HP and LP cylinder. Engine dimensions are given as follows:

HP cylinder, diameter	175 mm
LP cylinder, diameter	380 mm
Stroke	340 mm
HP valve, diameter	130 mm
LP valve, diameter	180 mm

Factory tests were made with a KV-5 boiler providing steam for the 18 kg/cm² portion of the trials and the KV-5M providing the necessary steam at 28 kg/cm². Results were reported as good, with the trial model developing from 200 to 330 horsepower at 200 rpm, depending on steam flow. At 400 rpm and maximum steam flow the engine indicated 550 horsepower.

Similar trials were held underway with the MP-10 engine installed in the *Bor* class tug. This tug, the designation of which comes from the first letters of the Russian words for "Tug, lake-river," is presently under construction in the Soviet Union for use on the country's lakes and rivers, and also on the new inland seas formed as the result of construction of hydro-electric installations. When one tug of this series was pitted against a similar tug with a TM-2 engine the results looked like this:

	Power, ihp		Pull, kg	
	Working	Maximum	Working	Maximum
Tug with MP-10 engine	540	680	7,000	8,050
Tug with TM-2 engine	475	560	5,800	7,400

Hence, as reported, the tests indicated that the MP-10 engine was able to increase the vessel's pulling power by some 20 per cent with some reserve left, whereas the TM-2 engine was forced to operate at maximum speed to obtain about the same power as the new engine.

Work is continuing on improving the design of the MP-10, both on the part of the designers and within the "Teplokhod" Works as well. This work includes efforts to improve steam utilization, increase the operational and technical dependability of the engine, and improve the technology of its manufacture.

NEW CONSTRUCTION

In July, 1956 the "Krasnyiy Don" Yard launched the first of a new type of cargo motorship designed for use on the internal waterways of the Soviet Union. It is reported to have a cargo carrying capacity of 150 tons and is powered by a type 3D6 engine which is rated at 150 hp. The designed speed of the vessel is 14-16 kilometers per hour. Controls are centralized in the wheelhouse, which is aft, providing unbroken hold space from the bow to the house. Hatch covers are of the telescoping type, mounted on ball bearings. A one-ton bicycle-type crane is mounted on the hatch coamings to handle cargo. It is further reported that the yard, as a result of the successful underway trials, will begin serial production based on improved techniques of building and will attempt to reduce the number of man-hours which go into building of the vessel, as well as attempt to lower costs.

The water-jet propulsion vessel is gaining favor in the Soviet Union because of its shallow draft, good maneuverability, and ease of maintenance. A cutter with the designator PS-1 was exhibited in the Timber Industry pavilion at the All-Union Industrial Fair in August 1956 and drew favorable comment. The vessel was reported to be 12.3 meters in length, 3 meters in beam, and drawing but 38 cm. The engine model is D-54, but no speed was cited. However, in view of the fact that the vessel was designed for use in timber rafting roadsteads, speed would be relatively unimportant as opposed to the need for maneuverability. At the same time pictures show a more powerful vessel of the same type on the Yenisey River in the vicinity of Krasnoyarsk. This vessel, called *Progress*, was built in the Yeniseysk Central Repair-Machine Shops and was successfully tested on the Angara and Taseyeva rivers. Rated at 300 hp, the vessel attained a speed of almost 20 km/hr. Draft, with a hull length of 26 meters and beam of 5.5 meters, is some 50 cm. The water-jet engine is reported to be the design of an engineer named Khrennikov, whose death was recently recorded.

Late in 1956 there occurred the dock trials and underway trials of *Krasnovodsk*, a 16,000-ton displacement tanker built, it is believed, in the I. I. Nosenko Shipyard in Nikolayev. The latest of the tankers, the new motorship reportedly was equipped with the latest in navigation and radio equipments. In the north the underway trials of a large refrigerator ship, the diesel-electric *Akmolinsk*, built in the Leningrad Shipbuilding Yard imeni S. Ordzhonikidzye, were held in the Baltic. A sister, *Kurgan*, was indicated as ready for sea, while yet another, *Zelenogradsk*, was reported ready for dock trials. Several others were on the ways, with *Ivan Stevanov* about to be launched. No specifications are available at this time.

The Gorkiy Shipbuilding Yard imeni V. Molotova sent a newly constructed motorship, not otherwise identified, all the way to the Dnepr River late in October 1956. The vessel was assigned to operation on the reservoir created as a result of the construction of the Kakhovka Hydro-electric Station.

The I. I. Nosenko Yard, previously indicated as the builder of tankers, early in September also completed underway trials of a diesel-electric vessel named *Dneproges* along the Black Sea coast. Designed for ice operations and fitted with powerful cargo handl-

ing gear, the vessel was assigned to the Murmansk Arctic Steamship Company to operate in Arctic waters. The picture accompanying the text revealed what appeared to be a standard tanker hull design and overall the vessel looked like a smaller version of what the Soviet Union terms a "super tanker."

Augmenting its own program of building, the Soviet Union has placed orders in many Western yards, as well as in the satellites, for standard types of river and ocean going ships, as well as for vessels of the technical fleet. Thus, the turbine driven *Nikolay Pirogov,* built in France, was operating in October. Earlier, in order to make the Northern Sea Route traverse, the East German builders had delivered to Arkhangelsk three new river passenger vessels with diesel drive. These latest additions were assigned to the Ob and Lena rivers to join four sisters previously sailed over the Route. Departing on 15 August, these vessels made the ninth traverse of river ships through polar waters, and were among more than twenty vessels leaving Arkhangelsk for the northern and Siberian rivers. Czechoslovakia recently provided a diesel-electric suction dredger named *Obskiy 18 DE-4.* Of interest is the report that the vessel is fitted with an instrument with the intriguing name of "gamma-spoil" meter. This instrument reportedly permits determination of the percentage of liquid in the spoil since it operates on the principle of absorption of gamma rays which are radiated by cobalt isotopes.

SHORE BASED RADAR

The use of shore based radar installations for the purpose of guiding both ocean-going and river vessels into their respective ports during periods of low visibility is currently enjoying experimental use in the Soviet Union. It is pointed out, for example, that in the Kola Gulf during 86 days in the period November, 1955 to February, 1956 there were about 64 days with heavy fog and snow storms in which ships could not move. To overcome this navigational difficulty, Soviet scientists drew upon Western practice in ports such as Liverpool, LeHavre and others and established, in 1954–55, in the port of Odessa on the Black Sea an experimental shore radar station utilizing the "Neptun" radar. Admitting the shortcoming of this ship-board type gear, the experimenters set about compiling a mass of data to substantiate the fact that this type of shore installation would be helpful during periods of low visibility.

In Odessa the experiments were conducted under conditions of, for the ship, "zero" visibility. This was done by shrouding the pilot house of the vessels used and forcing the navigators to rely solely on the ship's compass. The shore station operator, by means of a radio-telephone installation, communicated bearing and distance information to the ship, enabling the conning officer to set his course accordingly. Runs were made from 14 miles out, as well as from close in, with results reported as reasonably good. Improved results are expected with the advent of specially designed stations and equipment.

The Ministry of the Maritime Fleet has placed orders with the Soviet electronics industry to develop such a station and several such are planned for the Kola Gulf area. No actual progress is claimed as yet, however. The Odessa station, because of a lack of suitable radio-telephone communications, as well as certain failures in organization and training, has fallen into disuse.

At the same time, however, a station has been established under the cognizance of the Ministry of the River Fleet in the vicinity of the Kuybyishev Hydro-electric Station to assist in orderly movements of the fleet through the locks of the station. The vessels which have been used to prove experimentally the value of such a radar installation are motor tugs. They have been furnished with a special grid chart on which the navigator can chart his bearing and distance from the radar station and quickly compute his course to destination. Range at present appears to be limited to 12 miles. Operators cannot, yet, handle more than one ship at a time, but it is suggested that further training will enable the operators to handle simultaneously two ships moving in different directions. As in the maritime station this station also uses R/T Communications. The ultimate appears to be the use of a "lead" ship, the crew of which is trained to conn by compass only, to act as the leader to bring caravans into the locks safely and without loss of time and awaiting good weather.

OIL PIPELINE CONSTRUCTION

It is frequently difficult to assess the logistics capabilities of the various modes of transportation in the Soviet Union when internal arrangements are unknown. Thus, it is with considerable interest that we read of the coming into service of a petroleum pipeline deep within the Soviet Union. The most recent news of increased logistics capability is within the area known as the "Second Baku," a vast oil-bearing region between the Volga River and the Ural Mountains.

Prior to the construction of the pipeline, which runs a distance of 150 kilometers from Almetevsk to Chistopol, the crude was apparently brought out by rail from the fields to a loading point well up the Belaya River where it was loaded into barges. These barges were then towed to Derbeshka, in the vicinity of the juncture of the Belaya and Kama rivers, where the oil was transloaded into Volga River vessels for onward transportation to the refining and distributing centers in Astrakhan, Gorkiy and Yaroslavl. Complicating factors in this process included lack of water during certain periods of the year on the relatively shallow Belaya River as well as inability to load to full draft the large barges provided to bring out the oil.

It appears that much of the difficulty has been eliminated with the advent of the pipeline. Chistopol is the site of a relatively deep-water roadstead, in which the barges can be loaded to capacity, as well as the terminus of the regular line for the transpor-

tation of the oil to the centers already mentioned. Storage tanks have reportedly been installed on the banks of the Kama River in the Chistopol area and vessels can be loaded upon arrival.

Thus, the net result of the laying of the pipeline has been a reduction in the length of the run for the oil carriers, an increase in the number of trips which can be made by the assigned vessels as a result of the elimination of lost time waiting for and carrying out transloading operations, and, presumably, a reduction in overall cost.

TANK CLEANING

As refining processes improve, and as the by-products of that process are channeled into industrial, transportation and military end uses, the residues, or "mazuts" as the Soviets call them, become more viscous and more difficult to transport. Cleansing of carriers is required more frequently and, should operational demands require, complicates the problem of readying carriers to haul such diverse cargoes as edible oils, soybeans and grains.

Surprising as it may sound, the time consuming, and dangerous task of tank cleaning is done mainly by hand in the Soviet Union. The tankers, in general, expend thousands of man-hours on the task and the chief means for cleansing is plentiful use of steam and hot water. Even more difficult is the task of cleaning barges which are equipped with neither pumps nor electricity.

Soviet designers and engineers have attempted, in the past, to alleviate the dangers to health which exist for the tank cleaning crews (frequently the crews of the tankers and barges themselves are used) by the use of steam ejectors to ventilate tanks, as well as the installation of Butterworth-type units called "washing machines" and designated the M-1GP which lighten the work and speed up the washing. Despite such aids, however, when it becomes necessary to prepare for the loading of grains or light petroleum products, the cleaning process can require 20 to 22 days to complete, depending on the viscosity of the mazuts previously carried.

Soviet engineers are well aware of advances made in the field of tank cleaning in Western nations, and are equally aware of the products of the chemical industry used in the cleansing process. It is pointed out that a tanker which has carried a load of 13,000 tons of black oil can cleanse itself in 2 or 3 days abroad, as opposed to the length of time indicated for the Soviet Union, by the use of these chemicals.

Whereas the Soviet petroleum industry has developed synthetic surface-active washing agents (variously called OP-10, sulfanol, sulfonat, etc.) their production is still scant and cost is high. Relief has come, it seems, from a most unexpected source. The Ministry of the Maritime Fleet, which operates virtually all Soviet tankers, called upon the Moscow branch of the Institute of Greases (Fats) of the Ministry of the Foodstuffs Industry for help and received from the Institute a washing preparation called "tanker powder," a combination of washing agents and neutral electrolytes. The substance is reported to have good washing qualities, is an excellent degasifier, as well as a de-emulsifier, as a result of which the petroleum products are easily separated from the solution. After a standing period the oil can be drawn off and used as a fuel, the solution reused for further cleansing. Industrial production of the powder is to commence sometime soon as a result of a series of tests conducted with it.

The washing machine mentioned does not appear to render satisfactory service. Unclear is whether this is the result of poor design, improper use, or inadequate maintenance.

Plans for the future include the establishment of special cleaning stations, two small ones having already been set up in Baku and Astrakhan, both on the Caspian Sea. Odessa, Tuapsye, Novorossiysk and Nakhodka, the ports handling the ocean-going tankers, remain to be so outfitted. By the use of such stations, it is pointed out, the products of the cleaning process can be collected and utilized. Too, there would be a saving in time resulting from the use of specially trained personnel to handle the operations.

STANDARDIZATION

In December 1954 the Soviet Union made a decision to type and standardize all machinery, equipment and parts used on board the numerous types of ships which it carries in its registers. The effort was undertaken in order to speed up, and reduce the cost of, construction and repair.

Two years later the effort has culminated in a complete listing of machinery, equipment and parts, together with a list of the required equipment for building and repairing, for the so-called "serial" ships. These series include the *Kazbek* tankers, a variety of river types such as the *Moskvich* (a passenger motorship), tugs with 3D6 (150-hp) engines as well as dual engine installations furnishing 300 hp, 600 hp tugs of the *Krasnoye Sormovo* type, *Bolshaya Volga* type cargo motorships, 200 ihp and 400 ihp steam tugs, 60 ton cargo carriers for the shallow rivers and roadstead type motor tugs.

In all some 243 type-sizes were examined, from which 133 different types and sizes of mechanized equipments were listed. Accessories, piping and associated systems were reduced from 2700 to 1400 while 2200 parts, shipboard installations, and fittings were reduced to 1000. Listings of replacements for shipboard equipments which were considered unfit for serial ships were compiled and albums of plans showing the equipments which must be used in the design of new, as well as the modernization of old, ships have been drawn up.

Listings dealing with main and auxiliary steam boilers, internal combustion engines, diesel generators, compressors, heat exchangers, drive shafting, and equipments for vessels of the technical fleet (dredges, shalands, etc.) are being compiled.

There is, however, a wide disparity between the

drawing up of lists and the actual use of these lists in building and repair work. Necessary supplies of new and replacement units and parts are frequently not available to the yards and plants designated to carry out the required work. Additionally, technical divisions of ministries, steamship companies and lines, and of the yards and plants themselves, do not always provide the working man with the required plans and documents to enable him to shift over as planned. And, should all this be in order, the operators of the vessels frequently fail to schedule them into the right repair point in time to avoid freezing up in the ice, miles from their destinations, or fail to unload or clean them properly so repairs can be carried out.

ELECTRIC POWER SHORTAGES

One of the basic causes for the lag in development of many of the shipbuilding and ship repair enterprises, particularly those in the Volga basin, is the lack of, or shortage of, electric power. This is especially true of those plants and enterprises which are dependent on installed capacity, as opposed to those which draw upon the networks of the particular oblast or city in which located. Virtually all plants dependent on installed capacity are now unable to satisfy the demands of their installed load, or what is even more important, cannot install new machinery and equipment because the power supply is inadequate to operate such new installations.

A prime example is reported to be the "Pamyat Parizhskoy Kommunyi" Yard in Gorkiy. Despite the fact that the yard is one of the largest engaged in the repair of cargo-passenger ships, its power plant was built thirty years ago and consequently cannot supply anywhere near the needed power. The power plant manages to maintain voltage at about 180 volts, with the result that equipment fitted with automatic relays (lathes, shears, etc.) frequently trips out as a result of low voltage. Welding is particularly vulnerable, requiring as it does a steady power source in order to ensure good quality work. Compounding effects are experienced because needed new equipment cannot be installed, work must be curtailed, and, despite a shortage of lumber, the yard's sawmill cannot operate for more than one shift because of the lack of power. Hand work continues to predominate because the compressors needed to supply air for pneumatic tools cannot be installed.

Attempts to rectify the situation in this, and other yards, were made as early as 1954 when an order was signed to build a high tension line from Gorkiy to the yards in the area, but two years later, it is stated, nothing beyond drawing of plans has taken place because no money was allocated to build the line.

EDUCATIONAL FACILITIES

Despite great propaganda on the part of the Soviet Union with regard to its educational system and the number of trained personnel turned out by the system, not all such personnel are adequate for the tasks which are assigned to them after they finish school. Whether the fault lies in the personnel or the system which educated them is difficult to ascertain with any degree of exactitude—but let at least one of the educators speak for himself. Here is a quote from an article written by Professor G. Boytsov, of the Gorkiy River School:

> The Volga River basin and its tributaries contain seven river schools and technical schools. It would seem that these institutions, considering the length of time they have been in existence, could provide qualified specialists in sufficient numbers for the fleet. Yet the number of such in the ships sailing the Volga is insufficient. According to data provided by the Volga Combined Steamship Line there are not enough graduate specialists. Only 18 percent of the total number of captains, navigators, and engineers in the basin are graduate specialists. Where are the specialists that our institutions graduate each year? Young engineers do not have the practical experience needed to repair ships, navigators have insufficient knowledge. In addition, suitable living conditions do not prevail in many of the wintering places where the ships are laid up, with the result that many of the young men take up work ashore or shift over to enterprises in other ministries... We must, in the future, review the programs for practical work. This will improve the quality of preparation of the young specialists...

On the other hand, it is the same young specialist who, with maturity becomes an employee of one of the many institutions which cope with the various problems of shipbuilding, ship repair and water transportation. For example, in Moscow alone there are six planning-design and scientific-research institutions just for water transportation. These institutions employ some 2,000 scientific-research workers, designers, planners, technicians and draftsmen. The work of the individual institution is highly specialized and each assumes responsibility for a specific area or field of endeavor. Thus, the principle task of the personnel of an institute known as "Giproarktika" (a possible expansion for which is probably "State Institute for Arctic Planning and Research") is to work up planning-estimating and technical documents for capital construction in the Arctic region.

Nevertheless, the manpower shortage is becoming evident from rather interesting evidence. The same Gorkiy River School, an institution which was founded 70 years ago, has found it necessary since 1955, to take students from among those completing middle school and to cut the period of study in the school to 3½ years. Classes in these institutions are relatively small. The Krasnoyarsk River Technical School, which recently celebrated its 25th anniversary, graduated a class of 43 navigators and 48 engineers. Many of these go on to continue studies in either the Leningrad, Gorkiy or Novosibirsk institutes for water transportation engineers. Others, however, go directly to ships for duty. Yet other students come to the higher institutions from similar schools in Kuybyishev and other cities. The need to provide young men for institutions of higher learning appears to be having adverse affects at lower levels.

ENSIGN J. M. P. WRIGHT, JR.

HARBOR CLEARANCE: CASABLANCA TO NAPLES

THE AUTHOR

graduated from the United States Naval Academy in the Class of 1956. He is now serving in USS St. Paul (CA 73) in the Pacific Fleet. This paper was prepared as an essay during the author's first class year at the Academy.

INTRODUCTION

To MAINTAIN the volume of supplies necessary for the fighting efficiency of an army which is continually advancing from the beachhead is a major problem. The best solution to this problem is to obtain protected harbors which have facilities for the rapid unloading of cargo ships. In the invasions of North Africa and Europe during World War II, one of the early objectives was to obtain a harbor with the necessary facilities.* When the allied forces took these harbors they always found some degree of damage, caused either by their own bombing and shelling, or else by enemy sabotage. This paper is concerned with the problems, new techniques, and organization of the harbor clearance groups in the Mediterranean during World War II.

EARLY PROBLEMS

Prior to World War II, there was a lack of salvage equipment and trained salvage personnel in the English and American navies. This lack of equipment and personnel can be attributed to several factors. In England immediately after World War I, the Admiralty sold most of their salvage ships and equipment, and depended on civilian salvage firms for their major salvage jobs.† Likewise the U. S. Navy, never having had much salvage equipment, also depended on civilian firms.** Moreover after 1925, collisions, strandings, and other types of work for salvage firms were on the decline, due to better navigational aids and a wider acceptance of the International Rules of the Road.# As a result many salvage firms were forced out of business; at the beginning of the war there were only two firms in England * and one, Merritt-Chapman and Scott Corporation, in the United States. Contracts were made with these companies to do salvage work when required for the United States and British navies. This type of arrangement was satisfactory in peacetime since there were few major salvage jobs to be done on naval vessels.

As it became more and more evident that the United States would eventually be at war, the Navy Department realized that their salvage facilities would not be adequate to cope with the increase in salvage work brought on by a war. As a result Commander W. A. Sullivan USN (Ret.), who was working for the Merritt-Chapman and Scott Corporation, was called to active duty and sent to England to learn how the Royal Navy had been coping with the same problem. On returning, Commander Sullivan reported that the Admiralty had found their two largest problems to be first, the lack of trained personnel, and second, the lack of enough modern salvage equipment. To meet the urgent demand for a salvage force the Admiralty had taken over the two civilian firms, making their personnel members of the Royal Navy Volunteer Reserve.**

The Bureau of Ships planned to do basically the same thing as the British to solve the problem in the United States. But, proper legislation and the necessary funds had to be obtained from Congress. Since the new Naval Salvage Service was to be responsible for both publicly and privately owned vessels, legislation was necessary in order that public funds could be used to salvage privately owned vessels. The funds were to provide salvage vessels, crews, equip-

* E. O. Hauser, "Commodore of Sunken Ships," in *Saturday Evening Post*, 7 October 1944, p. 20.

† Captain J. B. Polland, RNVR, "Salvage of Ships and Clearance of Harbors," *The Engineer*, 9 March 1945, p. 197.

** A Short History of the Naval Salvage Service (Washington, 1948). Cited subsequently as "History."

Polland, p. 197.

* *Ibid*, p. 198.

** *History*, pp. 3-5.

ment, and technical assistance from private salvage firms. Congress passed the necessary bills on October 24, 1941, and a contract was made with the Merritt-Chapman and Scott Corporation on 11 December, 1941. The contract established a Naval Salvage Service which was to be manned by civilian personnel of the Merritt-Chapman and Scott Corporation. The Salvage Service was to be responsible for salvage work in and around the United States. The contract stipulated that the Salvage Service, in effect the Merritt-Chapman and Scott Corporation, was to help train naval personnel for salvage work.* When the contract went into effect, Commander Sullivan was made Supervisor of Salvage, to act as liaison between the Navy and the Merritt-Chapman and Scott Corporation; his main interest, however, was the training of naval personnel in salvage work.** The Naval Salvage Service was therefore the nucleus for training naval personnel for salvage work. Furthermore, the equipment obtained from the salvage firm was the basis for building up a surplus, which would be needed in later harbor clearance operations.

NORTH AFRICA

In July 1942 initial planning was begun for the North African invasion. At the time, it was realized that some type of salvage work would be necessary. However, the exact amount and type of equipment necessary for the operation was not known, because an amphibious operation of this magnitude had never been undertaken before. Furthermore, there was not enough salvage equipment in Allied hands to cover both the German submarine menace, which at this time was at its height, and also harbor clearance, which was the main concern of the planners. Therefore, some type of compromise had to be worked out.#

The Atlantic Coast of North Africa was initially considered a zone of American responsibility, and the Mediterranean Coast a zone of British responsibility. To handle harbor clearance and other salvage jobs in its area, the U. S. Navy ordered three vessels rigged for light salvage work to be included in the service forces for the invasion. The advanced salvage parties attached to these vessels were to make an estimate of the situation in the area and begin clearing the harbor at Casablanca. Meanwhile, Captain W. A. Sullivan## was to remain in New York, with salvage officers, divers, and special equipment until he received the advance party's report.† In the Mediterranean the Royal Navy was faced with the problem of where to get the necessary salvage personnel and equipment, for English salvage forces were already stretched to their limit trying to keep up with salvage work in the United Kingdom and Eastern Mediterranean. The Admiralty, badly in need of an experienced salvage officer, asked that Captain Edward Ellsberg, USNR, be sent from Massawa# to direct salvage operations at Oran (Chart I). He was thereby appointed chief salvage officer of the North African invasion forces by General Eisenhower.‡

The Allies landed in North Africa on 8 November, 1942. On receiving the report of the advance party, Captain Sullivan flew to Casablanca on 23 November with the necessary personnel and equipment. Here he established a salvage group of about a hundred men and divided them among Casablanca, Port Lyautey, and Feddhala. In Casablanca, the most important port in the American Zone, most of the damage in the harbor and along the waterfront had been done by the USS *Massachusetts'* sixteen inch guns while silencing the guns of the French battleship *Jean Bart.** There were twenty wrecks in the harbor and two sunken drydocks (Chart II). Only a few of these wrecks were a hindrance to immediate operational requirements; they were raised by patching their holes and openings, and then pumping compressed air into the airtight compartments. The larger floating drydock was raised and used for making temporary repairs to the ships that were damaged in the invasion by German submarines.†

The situation facing Captain Ellsberg in Oran was much more serious. He found, when he arrived in the area on 29 November, that he had only one salvage ship, the *King Salvor,* and a few American divers who were on loan to the Royal Navy. In addition the harbor was in worse confusion than at Casablanca (Chart III).

> There were twenty-seven French wrecks littering the harbor. Masts and stacks at crazy angles broke the surface of the harbor waters wherever one's eyes lighted—in most cases, the hulls, whether right side up, upside down, or on their sides were wholly submerged and invisible. A string of masts and smokestacks lay across the entrance to the inner harbor. There six ships, anchored in two lines nearly bow to stern, had been scuttled to block the port. Inside there were sunken destroyers, sunken submarines, sunken freighters, sunken passengers ships, sunken drydocks. Everything in the port had been scuttled before the surrender—across the entrance, in the fairways, alongside the quays—wherever in the opinion of the French naval commandant at Oran they would cause us the most trouble in reopening the port.##

The outer harbor was not blocked, however, and the French** had not done a good job in scuttling the six block ships in the entrance to the inner harbor. Thus, before Captain Ellsberg arrived in Oran, the crew of the *King Salvor* had been able to pivot the *Boudjmel* on its submerged stern. This operation cleared a channel sixty feet wide and twenty feet deep into the inner harbor so that half-loaded Lib-

* *Ibid*, pp. 7-12.

** *Ibid*, p. 22.

\# *Ship Salvage*, The Bureau of Ships, ed. (Washington, 1944), p. 4.

\#\# Sullivan was promoted to the temporary rank of Captain on 18 June 1942.

† *Ship Salvage*, p. 5.

\# Massawa was an Italian Naval Base, in Eritrea on the Red Sea, which was taken over by the English early in the war. An Anglo-American salvage group, headed by Captain Edward Ellsberg, had been sent to Massawa to repair the Italian harbor and ship facilities.

‡ Samuel Eliot Morison, *History of United States Naval Operations in World War II*, (Boston, 1954); II *Operations in North African Waters*, p. 251.

* Edward Ellsberg, *No Banners, No Bugles* (New York, 1949), p. 271.

† *Ship Salvage*, p. 5.

\#\# Ellsberg, p. 49.

** In Oran allied forces were strongly resisted by the Vichy French. The French port commander had already demolished the port facilities when Admiral Darlan told the French to cease resistance.

STRAIT OF GIBRALTAR
MOROCCO
ORAN
ALGERIA
ALGIERS
DELLYS
BOUGIE
PHILIPPEVILLE
BONE
BIZERTE
TUNIS
SOUSSE
SFAX
MALTA
MEDITERRANIAN SEA
MARSALA
PALERMO
LICATA
GELA
SICILY
CATANIA
AUGUSTA
SYRACUSE
SPAIN
SETE
MARSEILLE
TOULON
FRANCE
LEGHORN
ITALY
ANZIO
NAPLES
SALERNO
BARI

CHART I

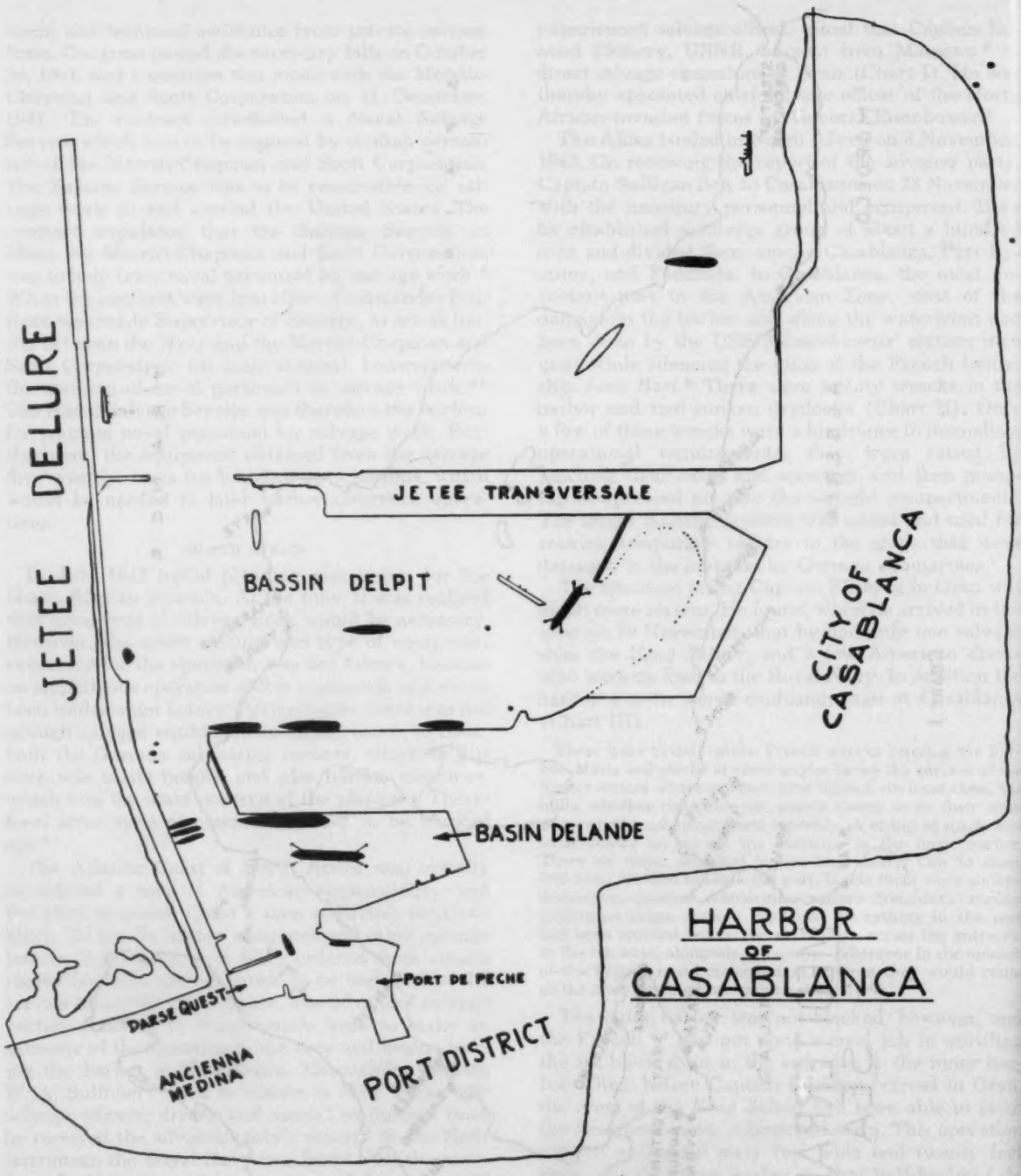

CHART II

erty ships were able to enter through the opening.

Captain Ellsberg's immediate concern was the coordination of the three salvage groups in the area, the British with their salvage ship *King Salvor*, the American divers, and a group of poorly equipped French divers; each of these groups was working on a separate job.† After he had coordinated efforts of these groups towards a common goal, Captain Ellsberg turned his attention to the enlarging of the opening to the inner harbor, leaving the clearing of the docks and restoration of the unloading facilities

† Ellsberg, pp. 62-5.

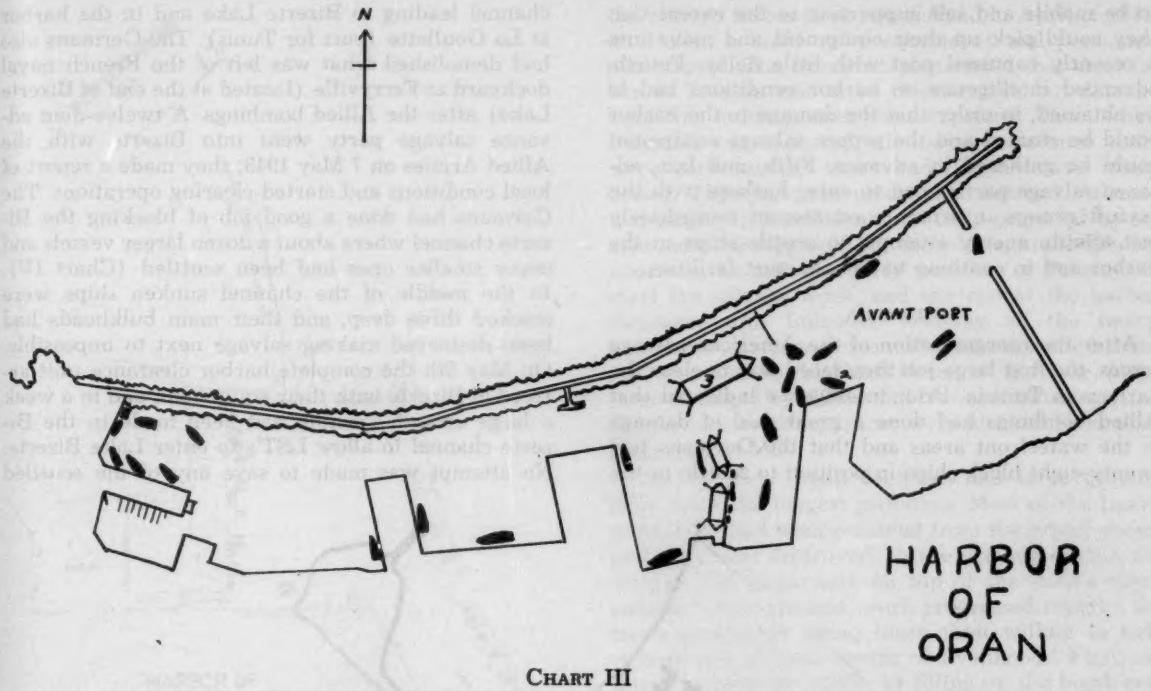

CHART III

1—Boudjmel
2—Spahi
3—Large Floating Dry Dock

to the Army Engineers. From the divers' reports Captain Ellsberg calculated that the entrance would be wide enough to handle any size ship if one more of the scuttled ships could be moved. Consequently, salvage operations were begun on the *Spahi* early in December. On January 7th, after patching a large gap in the ship's side and pumping compressed air into the hull, the salvage crew pivoted the *Spahi* on its stern and swung it into the inner harbor, clearing a channel one-hundred and fifty feet across.‡ In the middle of this operation, Captain Ellsberg obtained another group of divers and a salvage master from Massawa. He put them to work raising the 2400-ton floating dry-dock, which was badly needed in the area. The dock was raised on 13 January by the patching and pumping method which completed all the urgent work in Oran's harbor.*

In the meantime, the Allied Armies had advanced eastward capturing the ports of Philippeville, Bougie, and Bone. These ports were not designated to become major supply ports, and therefore, clearing them was not of great military importance. However, Royal Navy salvage units did undertake a few salvage jobs in them. Early in February Captain Ellsberg was relieved from his duties in North Africa and sent to the United States to get a complete rest after doctors had found that his heart had taken a severe strain.**

After Captain Ellsberg was relieved, plans for further operations and the growing size of the salvage forces made it necessary to reorganize them. Therefore, in April 1943, all American salvage units were combined into one task force (TF 84) and "Captain Sullivan was made task force commander with additional duty as Principal Salvage Officer on the staff of the commander-in-chief Mediterranean, and placed in control of all salvage activities in the area."† Task Force 84's principal base was established at Oran and later at Dellys, a town sixty miles east of Algiers.

By April 1943, a working doctrine had been formed for harbor clearance operations. First, the major concern in harbor clearance was removing obstacles in the harbor; saving the sunken ships was of secondary importance. As a matter of fact, it was often necessary to completely demolish a ship that could have been eventually refloated and repaired. Second, salvage jobs which had no effect on current military operations had to be left to local civilian contractors or to personnel of the permanently established base. Third, the harbor clearance groups had

‡ *Ibid*, pp. 295-8.
* *Ibid*, pp. 126, 132, 309.

** *Ibid*, pp. 366-7.
† *Ship Salvage*, p. 6.

to be mobile and self supporting to the extent that they could pick up their equipment and move into a recently captured port with little delay. Fourth, advanced intelligence on harbor conditions had to be obtained, in order that the damage to the harbor could be studied and the proper salvage equipment could be gathered in advance. Fifth, and last, advance salvage parties had to enter harbors with the assault groups in order to counteract immediately last minute enemy attempts to scuttle ships in the harbor and to continue to damage port facilities.

TUNISIA

After the reorganization of the American salvage forces, the first large job they faced was to clear the harbors in Tunisia. Prior intelligence indicated that Allied bombings had done a great deal of damage in the waterfront areas and that the Germans had twenty-eight block ships in position to scuttle in the channel leading to Bizerte Lake and in the harbor at La Goullette (port for Tunis). The Germans also had demolished what was left of the French naval dockyard at Ferryville (located at the end of Bizerte Lake) after the Allied bombings. A twelve-man advance salvage party went into Bizerte with the Allied Armies on 7 May 1943; they made a report of local conditions and started clearing operations. The Germans had done a good job of blocking the Bizerte channel where about a dozen larger vessels and many smaller ones had been scuttled (Chart IV). In the middle of the channel sunken ships were stacked three deep, and their main bulkheads had been destroyed making salvage next to impossible. On May 9th the complete harbor clearance unit arrived in Bizerte with their equipment, and in a week a large enough opening had been made in the Bizerte channel to allow LST's to enter Lake Bizerte. No attempt was made to save any of the scuttled

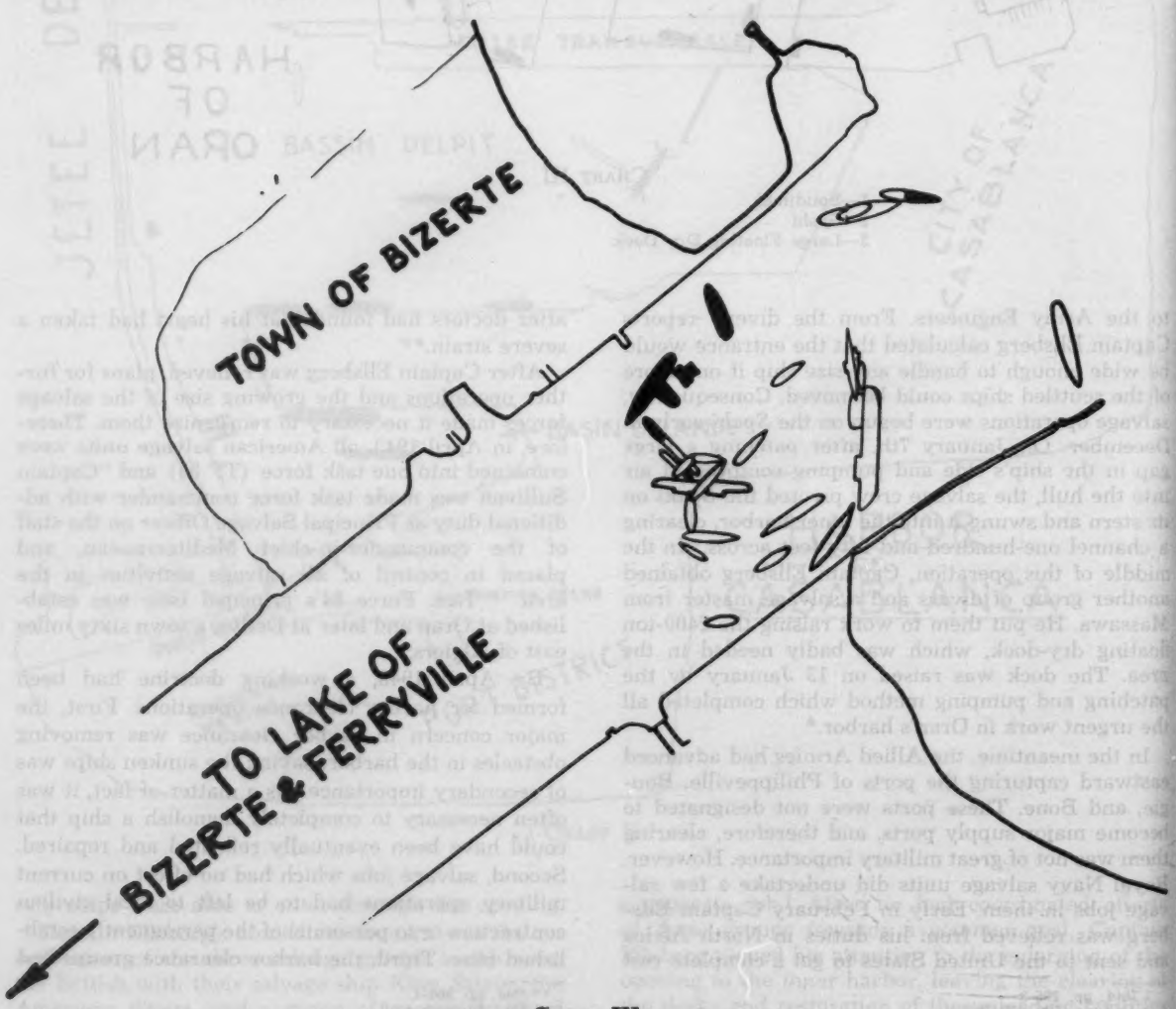

CHART IV
BIZERTE CHANNEL ENTRANCE

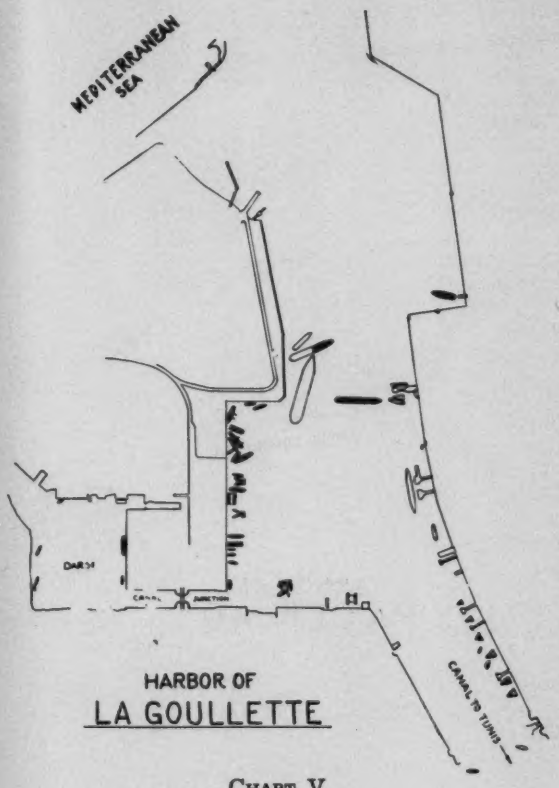

CHART V

ships; blasting was used to break up the vessels and they were then dragged to the sides of the channel. By early June the channel was cleared to a width of 140 feet and depth of 22 feet, permitting half-loaded cargo ships and coasters to enter Bizerte Lake.

In La Goullette there was very little major clearance work to be done (Chart V). One medium size coaster was scuttled across the channel and one half way in the channel. These vessels were blasted into sections with dynamite, and the sections dragged out of the channel.*

The dockyard at Ferryville (Chart VI) was a major one, having four graving docks and extensive repair facilities. Clearing and repairing of the graving docks was a long-term job, and, therefore, one not generally undertaken by harbor clearance groups. The Bizerte area, however, was to become a staging point for the imminent invasion of Sicily and Italy; and, as the repair facilities were needed urgently, Captain Sullivan's divers undertook the job of clearing one of the graving docks of three vessels. To complete the work in this area Captain Sullivan left only the minimum number of men, which he felt could be spared from future operations in Sicily.

SICILY

The original preparations for salvage operations during the Sicilian Campaign were begun just after the salvage forces were reorganized in April of 1943. At Dellys a build-up of equipment and personnel was started. The operation plan stated that the harbor at Trapani was to be cleared first, but damage here was much greater than expected. Thus, when Palermo was captured, all harbor clearance units were concentrated there and Trapani was abandoned. The clearance group that entered Palermo was largely self-sufficient, and fully prepared by recent aerial photographs for the job. As in the Bizerte operation an advance party was sent to Palermo to start the salvage work, and the rest of the harbor clearance unit followed, bringing all the heavy equipment. Salvage personnel found that the harbor entrance was not blocked; however, the four quays were damaged by Allied and German bombings, and some of the berthing spaces were blocked by sunken ships (Chart VII).

The harbor's repair facilities and large graving dock were the biggest problems. Most of the heavy machinery had been removed from the repair shops, and the shops destroyed. In the graving dock a destroyer had been sunk on top of the dock's spare caisson.* Nevertheless, work progressed rapidly, the city's population being more than willing to help restore one of their means of livelihood.† First, the quays were made usable by filling up the bomb craters and refloating some of the ships with Italian salvage pontoons that had been left intact in the harbor. The rest of the sunken ships were left in place; the superstructure was removed and platforms built across the deck to the quay. This allowed the unloading of transports, which would tie up to the hulks. This was the first time that this technique was used and it worked very satisfactorily. In the

* *Ibid*, pp. 9-10.

* Rear Admiral W. R. Carter and Rear Admiral E. E. Duvall, *Ships, Salvage and Sinews of War* (Washington, 1954), p. 259.
† Samuel Eliot Morison, *History of United States Naval Operations in World War II* (Boston, 1954); IX, *Sicily-Salerno-Anzio*, p. 188.

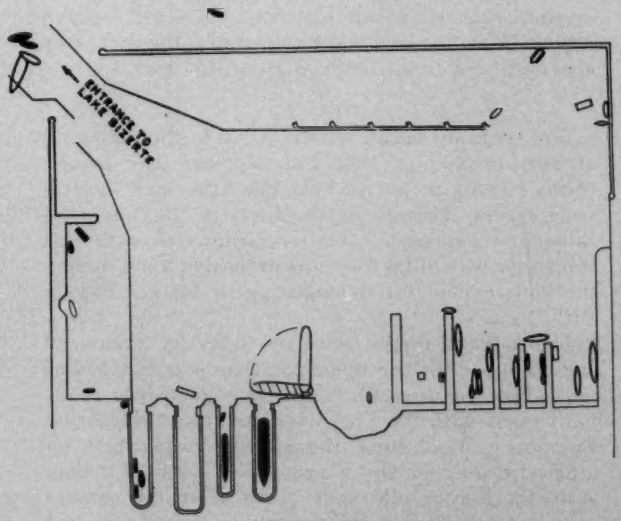

CHART VI
FERRYVILLE HARBOR AND DOCKS

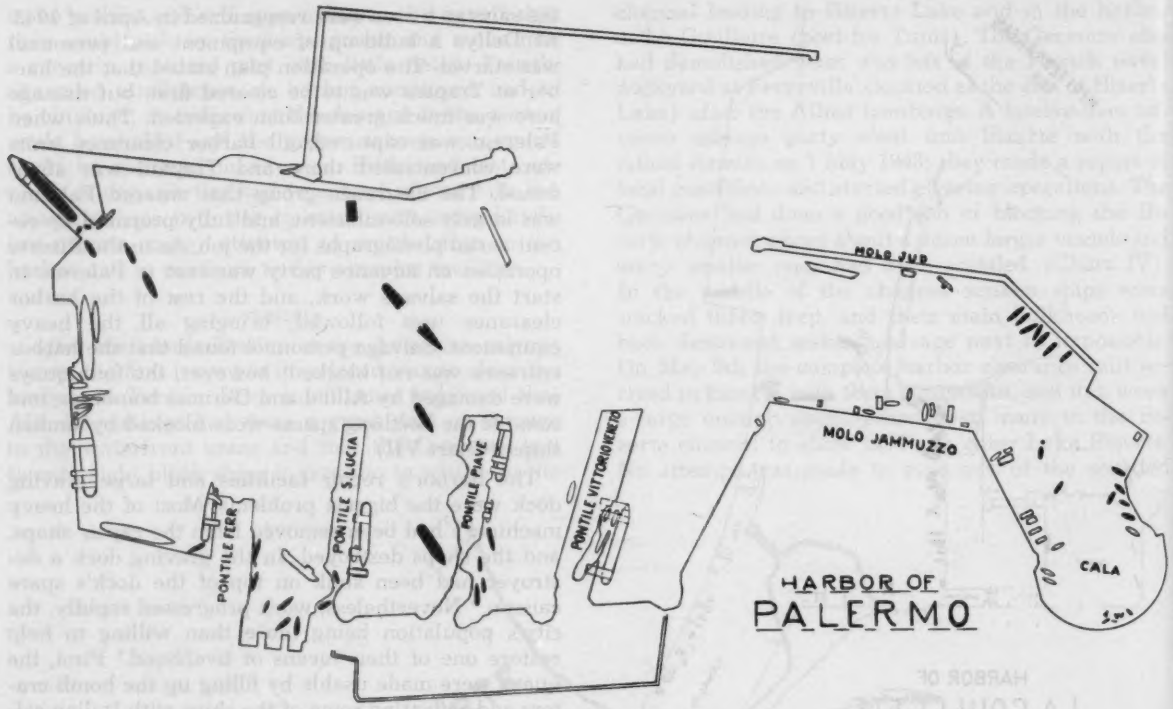

CHART VII

middle of the harbor two wrecks that were menaces to navigation were removed and the harbor was ready to handle Liberty ships on the 28th of July.

Some mention should be made of the work done on the graving dock, which itself was quite a salvage feat. The destroyer was raised enough so the spare caisson under it could be worked out. The caisson was then repaired and put in place of the original caisson, which had been damaged beyond repair. Next the dock was pumped dry, the destroyer repaired, and then removed from the dock.*

NAPLES

The build up began for the jump to the mainland of Italy in August, 1943. Palermo was used as one of the staging points for both the Army and the salvage forces. Though not realized at the time, the salvage work carried out in conjunction with this campaign was to be the most extensive done during the war, except for the clearing of Manila Bay in 1945.

The salvage forces were much better organized and equipped for this operation than at any previous time. For the first time, the salvage forces made joint plans with the Port Constructors of the Army Engineers. Also, since the salvage forces had increased tremendously in size, it was possible to separate the harbor clearance group from the combat salvage team. Previously, the same group of men had done both jobs, which placed a great strain on salvage personnel. Now the harbor clearance group could go into a harbor fresh, and the combat salvage team could be relieved or sent to minor and less strenuous jobs.*

The type of equipment gathered was governed by the shallow water in Naples harbor, which made demolition of wrecks impossible. The use of explosives to remove wrecks would have scattered pieces over the bottom, decreased the depth of free water, and made the pieces harder to find and pick up. Therefore, a great number of lifting vessels and heavy rigging had to be assembled for the operation. The most useful lifting vessels were British boom defense ships that drew very little water and could lift one-hundred and fifty tons off the bottom.**

The landing at Salerno was on 9 September, 1943, but it was not until three weeks later on 1 October that Allied forces entered Naples. Until Naples harbor was cleared, the 5th Army was supplied over the beach at Salerno; there the combat salvage team was very active keeping the beach clear of damaged landing craft.† In the meantime, salvage personnel daily had been studying aerial photographs of the Naples harbor, noting with much distress the results of the allied bombing.‡ On 10 October, Commodore Sulli-

* *Ship Salvage*, pp. 11-12.

* Carter, *et al*, p. 268.
** *Ibid*, p. 319.
† *Ship Salvage*, p. 13.
‡ *Opening up of Port of Naples* (Naples, 1944), report of Commander W. A. Doust, RNVR, to Flag Officer, Western Italy, p. 1.

van* and a small salvage party entered Naples by truck from Salerno. The harbor was a scene of complete devastation, the water covered with oil and floating debris, with hundreds of vessels strewn about the harbor (Chart VIII). All seventy-three electric cranes, except one, had been toppled into the harbor.

> The wrecking of these vessels had obviously been supervised by an expert with a knowledge of salvage, for each vessel had been systematically destroyed internally in the way of bulk-heads, and then so badly "blown" as to preclude use of either pumping or compressed air. Over each sunken vessel the enemy invariably sunk a few lighters, a dock crane, an occasional locomotive or a string of trucks, upon which wagon-loads of ammunition, oxygen bottles, and small arms had been discharged in a haphazard manner. This supertangle of obstructions had been created in order to involve intensive diving operations even after the main objective had been reached. It moreover appeared that the vessels had been sunk in such a manner as to remain invisible from the air.*

An interesting point is that no attempt was made to block the harbor as was done in North Africa. Damage to the city indicated that the Germans had a secondary motive in the destruction of the port facilities, which was the attempt to ruin the economy of Naples by destroying its means of livelihood.** On the afternoon of their arrival Commodore Sullivan and Commander W. A. Doust, RNVR, (English salvage officer in area) met with Major General G. D. Pence and Rear Admiral J. A. U. Morse, RN (Port Commander). It was decided that the American salvage forces would clear the eastern half of the harbor including the drydocks, and the English would clear the western half; salvage vessels and other equipment would be pooled as necessary. The priority of jobs and berthing availabilities were also established.†

There were no single spectacular salvage feats in the clearing of Naples; however, the job was very time consuming, requiring hard work on the part of the salvage personnel. By 5 October, four berths on pier "A" (Chart VIII) large enough to accommodate Liberty ships were open. The wrecks in these berths had been mostly sailing ships. Very few of the wrecks were actually salvaged; most of them were raised off the bottom by lifting vessels and deposited in graveyards established in out-of-the-way spots in the harbor. On some of the larger ships, the superstructure was partially removed and platforms built to the piers. This relieved the harbor clearance group of a great burden since the Army Engineers could do this work. By 10 October, the two drydocks were in use; they had been cleared by divers and repaired by the Port Constructors. At this time the first of a large number of dock workers and skilled laborers had returned to Naples and were willing to help repair the harbor facilities. From some of these workers several salvage parties were formed which worked along with Allied personnel in clearing the harbor.

Another meeting was held with the Port Commander on 10 November and a new goal of twenty-two Liberty ship berths was established. This was a large task, so the salvage officers designated more ships to be bridged over by the Port Constructors. By the middle of December, thirty berths were cleared, and the harbor was handling more tonnage than its maximum capacity before the war.* On February 29, 175 wrecks had been removed and for all practical purposes the harbor was clear. At this time a great deal of the salvage work was being done by Italian salvage personnel, supervised by Allied salvage experts.** As a tribute to the work the harbor clearance group had done, Admiral H. K. Hewitt said, "The restoration of the port of Naples so as to accommodate the deep-draft vessels necessary for the support of Allied armies staging through it was an unprecedented achievement of Operation Avalanche." †

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Morison, Samuel E., *History of United States Naval Operations in World War II.* Vols. II and IX, Boston, 1954.

In his colorful style Morison tells the more interesting details of some of the harbor clearance operations. From the salvage point of view, though, he does not mention the more important facts. Both volumes are helpful in determining dates of different operations.

Treatises

Carter, Rear Admiral W. R. and Duvall, Read Admiral E. E., *Ships, Salvage, and Sinews of War,* Washington, 1954.

The book deals with the logistic problems that the U. S. Navy faced in the Atlantic. They wrote it on the request of the President of the Naval War College, that a history of logistics in the last war be prepared. In writing this book, the authors had access to all of the official records, but they did not footnote the book; therefore, a check of their source material is not possible. The book mentions all of the important harbor clearance projects, and goes into more detail on Palermo and Naples.

Ship Salvage, Washington, 1944.

This pamphlet was printed for use at the Naval Salvage Training School. It was based on a report by Commodore Sullivan to CNO dated 31 January, 1944, and a Bureau of Ships letter of 15 August, 1942. Part I of the pamphlet is a "description of development and analysis of ship salvage, harbor clearance (wreck removal), rescue and fire fighting activities in the American and Mediterranean theaters."

\# Sullivan was promoted to the temporary rank of Commodore on 27 May 1943.

* Doust, p. 1.

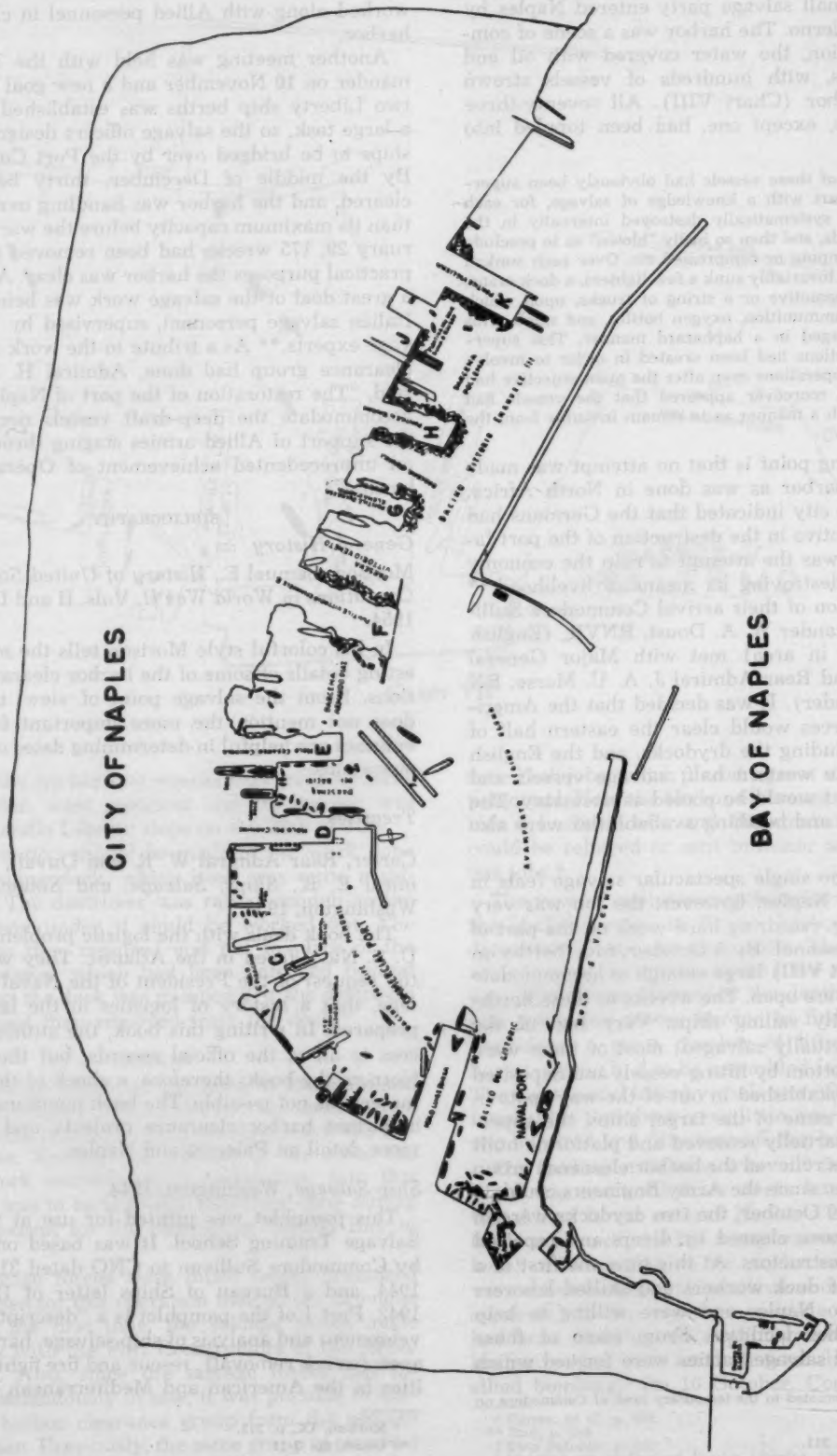
** Morison, IX, p. 311.

† Doust, p. 2.

* Morison, IX, p. 312.

** Doust, pp. 3-11.

† Carter, *et al*, p. 320.


CITY OF NAPLES
BAY OF NAPLES
CHART VIII
NAVAL PORT
COMMERCIAL PORT

A Short History of the Naval Salvage Service, Washington, 1948.

This Navy Department publication discusses in great detail the early development of the American Salvage Service.

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Ellsberg wrote this book for the popular market. Therefore, the book is not a scientific publication dealing in facts but a novel dealing more in personal feelings. The book gives Ellsberg's account of his part in the clearing of the harbor at Oran.

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Hauser, E. O., "Commodore of Sunken Ships," in *Saturday Evening Post,* 7 October 1944; p. 20.

A very interesting biography on Commodore Sullivan.

Polland, Captain J. B., RNVR, "Salvage of Ships and Clearance of Harbors," in *The Engineer,* 9 March, 1945; p. 197.

An article on salvage work in England and the work of the Royal Navy salvage group in the Mediterranean. A very good description of English salvage problems and their solution early in the war.

The Philadelphia Electric Company has under construction an electric generating station which will convert over 40% of the fuel energy into electrical energy—an overall plant efficiency which is 3% in excess of any existing plant. The throttle steam conditions are 1200°F at 5000 psi, supplied by a forced circulation boiler containing 150 miles of boiler tubing.

* * *

The Hamburg Association for the Utilization of Atomic Energy in Shipping has placed an order for the construction of a nuclear-reactor plant suitable for a 10,000 s.h.p. ship installation.

Benefit Association Established For Enlisted Men

A non-profit benefit asociation, open to "regular" enlisted personnel of all branches of the service has just been organized.

The Association was formed by a group of senior enlisted men stationed in and around Washington, D.C., who wished to provide themselves and all other service men and women on active duty with the same benefits and opportunities available to Commissioned Officers and Warrant Officers through the Armed Forces Relief and Benefit Association, established in 1947.

Created to advance and safeguard the economic interests of service personnel in all parts of the world, the Armed Forces Enlisted Personnel Benefit Association will initially offer its members emergency loan privileges, scholarship grants to deserving children of members, and low-cost group life insurance.

Because of the great interest in family security, a $10,000 group life insurance plan is being offered to supplement the benefits provided by the Survivors Benefit Act, where necessary. Additional benefits are contemplated as membership increases.

All Officers, Directors, and Advisors of the organization are serving without compensation in their capacities. Major General Robert S. Moore, USA, will act as advisor to the Association.

The control of the Association is vested in the membership who annually elect a Board of Directors. The Board of Directors, composed entirely of enlisted personnel, contains representatives from each of the services. The Association has no salesmen or agents and depends mainly upon its members to secure new members.

Under present membership eligibility rules, once a man qualifies for membership in the Association, his eligibility continues so long as he remains on active duty, regardless of his status.

Information concerning the Association and applications for membership may be obtained by writing the Armed Forces Enlisted Personnel Benefit Association, 422 Washington Building, 15th Street and New York Avenue, N.W., Washington 5, D.C.

GEORGE J. RASCHER

THE SELECTION OF A SHIPBOARD AUTOMATIC COMBUSTION CONTROL SYSTEM

THE AUTHOR

graduated from the United States Merchant Marine Academy, Kings Point in June, 1951, receiving his Bachelor of Science Degree and Third Assistant Engineer's license. Following his graduation, the author sailed actively aboard ships of the merchant marine until he entered into active naval service in March, 1953, as a Lieutenant Junior Grade. During his tour of active duty, the author served as Engineering Officer of the USS Douglas H. Fox (DD 779). Since his release to inactive duty, the author has been employed as a control and instrument engineer. In this capacity he has engaged extensively in work involving shipboard boiler and pump controls and instrumentation. The author is a previous contributor to the JOURNAL.

WHAT IS AN automatic combustion control system? An automatic combustion control system is a system of sensing and controlling components which are combined to regulate the firing of a boiler with little or no human assistance. A system is in actual automatic operation when it functions completely without human assistance.

Many of the advantages of automatic combustion control systems in stationary plants are self-evident. Some advantages of the shipboard use of automatic combustion controls are not quite as obvious. Briefly, these additional advantages are:

(1) Increased combustion efficiency over the wide range of steaming rates required of naval ships.
(2) Operation which reduces the element of human error during rapid fluctuations in boiler steaming rates.
(3) Increased protection for plant machinery.
(4) Reduced shipboard maintenance costs.
(5) A factor of safety in combat action.

Combustion efficiency is the ratio of the boiler heat output compared to the boiler heat input. Maximum efficiency is obtained when a boiler is fired to give the best possible combustion. Flue gas analysis is the most positive indication of combustion efficiency. It is generally conceded that the maximum combustion efficiency is achieved when an automatic control system is used because the system is more capable of maintaining the proper ratio between fuel and air under all operating conditions than fireroom personnel are capable of doing in firing a boiler manually. In time of war it is an absolute necessity to operate all ships at their peak efficiencies. This is particularly true since, in the event of another war, some or much of our present oil supply might be no longer available.

The very fact that an automatic combustion control system maintains better combustion conditions than can be obtained by manual boiler firing shows that human operating error is reduced. However, automatic control does not reduce personnel standards. Operating personnel must be trained to a higher degree when automatic controls are employed. This is true because additional elements are introduced into the ship's power plant design, and to eliminate costly equipment casualties, operating personnel must be readily able to recognize possible failures in the control circuits and take appropriate corrective action. In addition, the introduction of additional control equipment increases the maintenance burden of fireroom personnel. As automatic combustion control systems become more widely used aboard combatant ships, there may be agitation

within naval circles for the creation of a new rate—that of control technician.

When possible human error is eliminated, there is a resultant increase in the protection which is afforded to the ship's machinery. Further protection is afforded to the machinery since a continuous supply of dry steam at the prescribed pressure and temperature is furnished to the propulsion machinery at all times.

Since an automatic combustion control system insures the best possible boiler combustion conditions, eliminates possible human error and reduces boiler and machinery casualties, maintenance costs are reduced. The time spent in effecting repairs is reduced. The incidence of cleaning boiler firesides as a normal maintenance procedure is less, since optimum combustion conditions are maintained continuously.

Finally, a factor of safety in combat action is introduced when auto-combustion control equipment is employed. Since the navy requires that component elements of the system must be shock and vibration proof, the system may continue to operate although the ship suffers a hit that might be fatal to operating personnel.

The need for automatic combustion control for combatant ship boilers is now recognized. These systems have long been used aboard auxiliary type ships. However, the selection of an individual control system is dependent upon numerous factors:

(1) The overall operational requirements of the ship.
(2) The specific requirements of the boilers.
(3) Boiler conditions which must be controlled.
(4) The associated equipment furnished with the boiler.

It is a well known fact that a combatant ship, such as a destroyer, must be far more maneuverable than an auxiliary ship, such as an oiler. A positioning combustion control system may be perfectly adequate for the control of a tanker's boilers where fewer and less rapid speed changes are required in normal operation. On the other hand, a destroyer would probably require a feedback control system for satisfactory boiler operation to meet the ship's operational commitments.

In a positioning type automatic combustion control system, the firing rate is dependent upon boiler load. As boiler load, the demand for boiler steam output, varies, there is a corresponding variation in the level of the controlled variable, the quantity which is being controlled. Simply, this means that boiler pressure will vary with ship's speed.

A feedback control system eliminates variations in the controlled variable. This is accomplished by providing a continuous means of feeding any error in the controlled variable to the controlling components which make corresponding readjustments in the system to return the controlled variable back to the set point. Set point is the level at which the controlled variable is to be maintained; error is the difference between the actual value of the controlled variable and the set point. Thus, in a feedback control system, boiler steam pressure is maintained at a constant value regardless of boiler load. For this reason, feedback systems are more satisfactory than positioning systems and are invariably used where a very slight increase in initial cost is relatively unimportant.

The selection of a shipboard automatic combustion control system generally depends on more important factors than initial cost. The requirements placed on the boilers by the ship's propulsion plant are extremely important in determining much of the control system design. Set point, proportional band, proportional control response, reset control response and stability of individual components are different in systems where boiler steam load fluctuations are different.

It is well to define some of the terms which are commonly used in control work:

Proportional Band is the amount of change of the controlled variable which is required to cause a controller to go through its full output range.
Sensitivity is the ratio of the output response of a controller to a specified change in the controlled variable.
Stability is the reciprocal of sensitivity.
Resolution Sensitivity is the minimum change in the controlled variable which produces an effective response in the output of a controller.
Threshold Sensitivity is the lowest level of the controlled variable which produces an effective response in the controller output.
Proportional Control Response is controller output proportional to the error in the controlled variable.
Reset Control Response is controller output proportional to the average error in the controlled variable times the elapsed time during which the error occurred.
Rate Control Response is controller output proportional to the rate of change of the error in the controlled variable.

The boiler conditions which are to be controlled determine to a great extent what components are used in an automatic combustion control system. The system components must be constructed of material which will withstand the maximum operating pressures and temperatures to which they might be subjected. The components must also be designed to fit the ranges of the controlled variables within the system.

Boiler design must be considered in the selection of a combustion control system. An example is the case of integral and separately-fired superheater boilers. In the case of an integral-fired superheater boiler, the control system is normally designed to control boiler drum or steam header pressure; the superheat temperature would vary with boiler firing rate.

In the case of a separately-fired superheater boiler, the control system would have to be designed to maintain both a constant pressure and a constant superheat outlet temperature. This would be accomplished by designing the control system to fire the saturated side of the boiler furnace on the basis of steam pressure. The control system would then be designed to fire the superheater side of the boiler on the basis of superheater outlet temperature.

The associated equipment furnished with a boiler

is sometimes determined by the automatic control system. Transmission mediums in control work are numerous. However, the two accepted mediums for naval usage are compressed air and electricity. Compressed air is the most widely used transmission medium. The requirements of a pneumatic control system in regards to the quantity of compressed air used generally determines the capacity of the ship's air compressors.

In some cases the control system must be fitted to suit the associated boiler equipment. The associated equipment which must be primarily considered are blowers and burners.

If a ship is fitted with constant speed, electric-driven blowers, air for combustion must be controlled by regulating the position of either inlet or outlet blower dampers. If the ship is equipped with variable-speed, steam-driven blowers, as is commonly the case with combatant ships, combustion air may be controlled by controlling blower speed.

If the automatic combustion control system must have a rapid rate of response as determined by the ship's speed requirements, the control system may be designed to control air for combustion by positioning dampers in conjunction with varying blower speed. If an automatic signal is transmitted to change damper position, an immediate change in combustion air flow to the boiler results. However, if an automatic signal is transmitted to change the position of a blower throttle valve, there is no immediate change in combustion air flow to the boiler. Although throttle valve position changes with the automatic signal change to vary the steam admitted to the blower, blower speed is not immediately effected. The time delay results from the fact that the inertia of the blower moving parts must be overcome before a resultant change in blower speed can be effected. For this reason a blower is considered an inherently slow control device.

When damper position is controlled in conjunction with blower speed, feedback is normally employed to insure an air flow that matches the demand for air flow. When a change in combustion air flow is demanded by the control system, the damper is positioned to give an immediate change in air flow to the boiler and satisfy the demand of the system. At the same time, blower throttle valve position is changed by the automatic signal. As the blower speed responds to a change in the throttle valve position, the feedback in the system repositions the dampers to maintain a flow of combustion air that continuously satisfies the demand of the system. An automatic control system that controls combustion air in the above manner realizes two important advantages. A rapid rate of response is guaranteed by controlling damper position. At the same time maximum plant efficiency is obtained by controlling blower speed.

The problem of controlling combustion air is similar in stationary and shipboard work. However, some of the problems encountered in stationary plants are absent aboard naval ships. Since naval boilers are generally of the pressure type, the problem of incorporating control for negative furnace pressure is not required in naval boiler automatic combustion control systems.

Various fuels are used in stationary plants. All types of coal, gas, oil and coal tar are used in stationary plants. Often, stationary boilers require a combustion control system for the multiple firing of fuels. Aboard naval ships the only fuel that must be considered is fuel oil. To further simplify matters navy special oil is invariably used. Control manufacturers inevitably incorporate a means of easily varying the fuel-air ratio in the event that a ship may be operating in an area where navy special oil is not available. This allows the ship to operate with its automatic combustion control system in operation without making any major change in the calibration of any of the instruments in the system.

The type of oil burner furnished with a boiler influences the selection of the components which are used in an automatic combustion control system. Burner characteristics vary with different types of burners, and burner characteristics must be given the utmost consideration by the designer of an automatic combustion control system.

Burner manufacturers must consider flow-turndown and atomization in designing burners. The general classification of burners in regards to atomization is as follows:

(1) Air Atomization.
(2) Mechanical Atomization
    (a) Pressure Type.
    (b) Return Type.
(3) Steam Atomization.

Air atomizing burners are rarely found in plants of any size. A reasonably good turndown ratio is realized with this type of burner, but the use of air atomizing burners is limited because a high power requirement is essential to compress the air to give satisfactory atomization.

Mechanical atomizing burners are most frequently used aboard naval vessels in order to reduce the power requirements that are needed with air and steam atomizing burners. In addition, no additional requirement for make-up feedwater is imposed on a plant that employs mechanical atomizing burners as is the case with steam atomizing burners.

Pressure-type mechanical atomizing burners have been widely used in the past aboard naval ships. In this type of burner, all of the oil supplied to the burner is burned in the boiler furnace. In order to vary total oil flow to the boiler the supply pressure must be changed by changing oil supply control valve position as results from a change in total oil demand as determined by the automatic control system.

This method of changing the supply pressure to the burners to change the firing rate is effective as long as the burner has a sufficient turndown ratio to satisfy the demand for oil flow. When this demand

cannot be satisfied in this fashion, the numbers of burners in use in the boiler must be varied. If varying the number of burners in use does not give adequate results in oil flow to the burners to satisfy the demand, the size of the sprayer plate must be changed. A fuel-air ratio relay is incorporated in the automatic control system to compensate for these changes in burner tip size and the variations in the number of burners in use.

Oil flow to a boiler using pressure mechanical burners varies directly as the number of burners in use and directly as the square root of the pressure ahead of the burner. This relationship is shown in Figure 1, a curve of burner oil flow to burner oil supply pressure for a boiler having five burners.

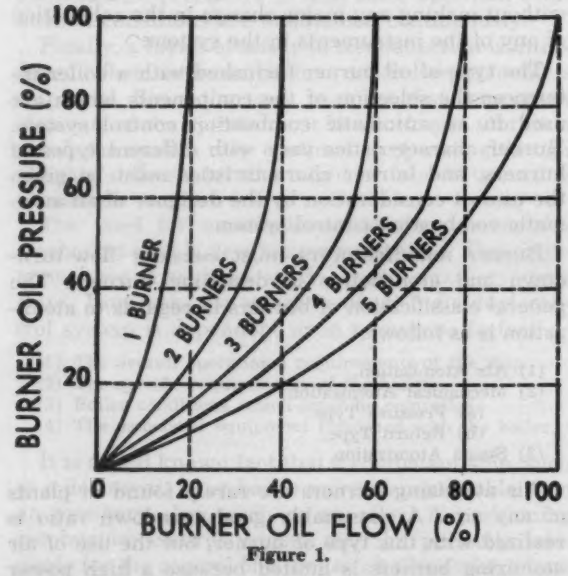

Figure 1.

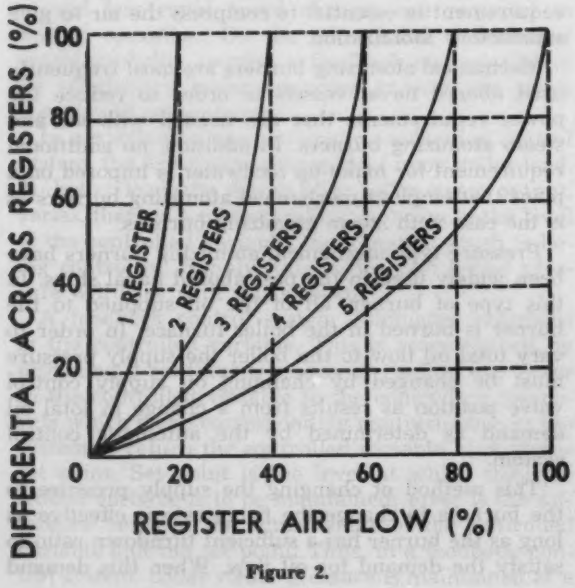

Figure 2.

If air flow through the registers of the same boiler is considered, it will be noted that a similar relationship exists between total air flow to the boiler furnace and the differential pressure across the burner registers. This relationship is illustrated in Figure 2.

For proper combustion, air flow must be directly proportional to oil flow. Considering the air and oil flow characteristics of a pressure mechanical atomizing burner, it can be noted that these flows are directly proportional when burner oil pressure is directly proportional to the pressure drop across the air registers. A curve of oil supply pressure versus differential pressure across the air registers of a mechanical atomizing burner of the pressure type is shown in Figure 3.

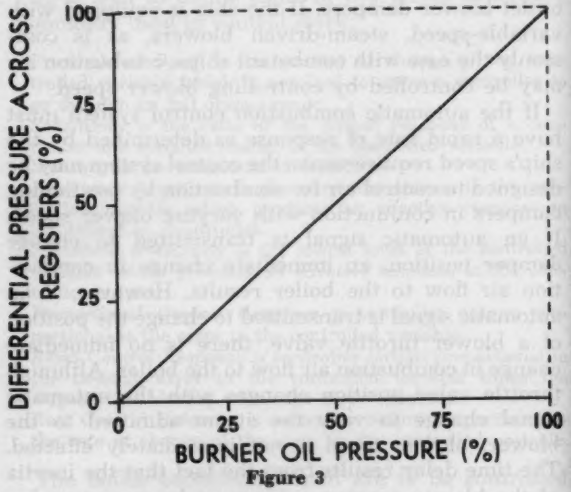

Figure 3

Once the burner characteristic is determined, it is possible to select the components required in a control system to perform particular functions. Therefore, with pressure mechanical atomizing burners, a linear transmitter would be used for sensing either oil or air flow to a boiler. This transmitter would be used in turn to control the other medium of combustion, air or oil, depending upon the overall selection of the control system.

Components of a control system cannot always be interchanged with different types of burners. In using return-type mechanical atomizing burners, a modification is required to a control system that would be used with pressure-type mechanical burners even if the overall selection of the two systems is identical.

A return-type mechanical burner is employed where higher oil flow turndown ratios are desired. A higher turndown ratio makes boiler operation more flexible in that the firing rate can be varied without requiring that burner sprayer plate size or burner combinations be changed as often as with burners of lower turndown ratios.

In order to control the firing rate of a boiler with return-type burners, the return oil control valve is

positioned to regulate the amount of oil returned from the burners. By varying the return flow of oil, oil available for combustion within the furnace is varied.

However, the control system used with return-type burners must be designed to also control supply pressure in some manner. Supply pressure must be controlled in one of the following ways depending upon the type of burner used:

(1) Constant supply pressure.
(2) Constant differential between return and supply header pressures.
(3) Variable differential pressure between return and supply header pressures.

A constant supply pressure can be easily and accurately maintained by employing a spring-loaded constant pressure regulating valve, installed in the supply oil line.

If a return-type burner requires that a constant differential pressure be maintained between the return and supply headers, a spring-loaded regulating valve would normally be installed in the supply header. This valve would use a feedback pressure from the return oil header on the diaphragm of the regulating valve. The feedback force, created by this pressure, would be opposed by the spring setting of the regulating supply valve. The amount of valve spring bias would determine the constant differential pressure that would be maintained between return and supply headers under all firing conditions.

The highest flow turndown that has thus far been achieved practically in burner design was through the usage of return-type mechanical atomizing burners with a variable predetermined differential between the return and supply oil pressures. In this type of control system, as shown in Figure 4, a signal for oil demand is used to position the return oil control valve directly. The same automatic signal of oil

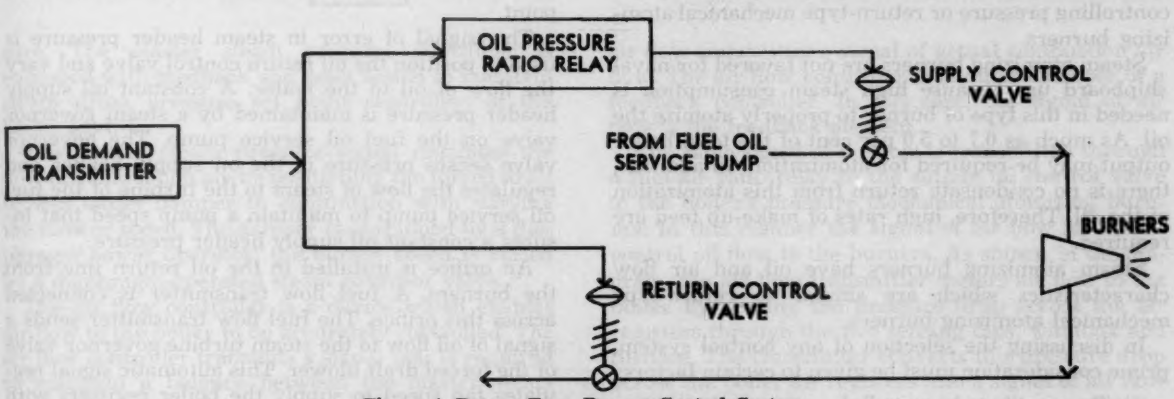

Figure 4. Return-Type Burner Control System.

demand is ratioed through an oil pressure ratio relay to position the supply oil control valve.

The relationship that exists between the return and supply pressures in the system illustrated in Figure 4 is depicted in Figure 5. The slope of the supply pressure curve in Figure 5 is determined by the setting of the oil pressure ratio relay. This setting is determined by the burner pressure characteristic. The slope of the oil return pressure curve is determined by the oil return control valve design characteristics.

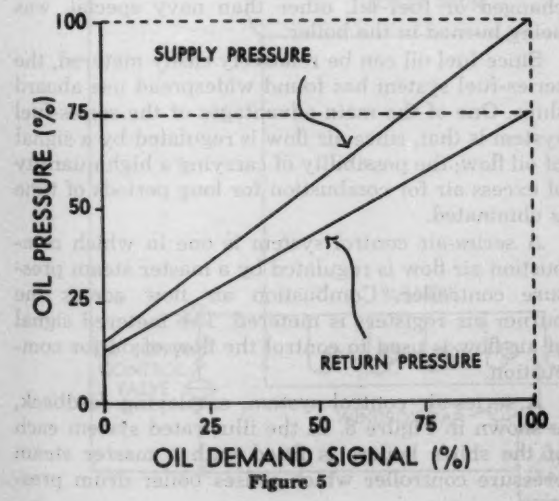

Figure 5

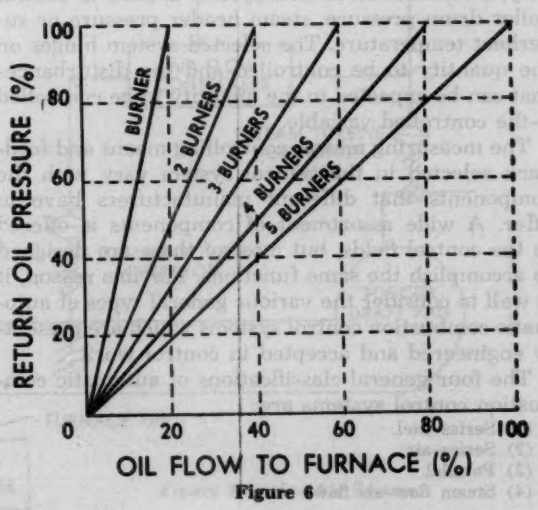

Figure 6

In any type of return mechanical atomizing burner, the oil flow to the boiler furnace is directly proportional to the pressure in the return oil line. Figure 6 is a curve of oil flow to the furnace of a boiler in respect to the return oil pressure in a boiler having five return-type mechanical atomizing burners.

Air flow through the registers of a return-type burner is proportional to the square root of the differential pressure across the air registers. The curve of air flow through these registers is identical to the curve for pressure-type mechanical atomizing burners. This curve is illustrated in Figure 2.

It can now be noted that the oil and air transmitters employed in an automatic combustion control system, fitted with return-type burners, must have a means of extracting the square root of the differential pressure which either senses. In many cases this modification in the transmitter may be the only difference that is required in the control circuits controlling pressure or return-type mechanical atomizing burners.

Steam atomizing burners are not favored for naval shipboard use because high steam consumption is needed in this type of burner to properly atomize the oil. As much as 0.7 to 5.0 per cent of the total boiler output may be required for atomization. In addition, there is no condensate return from this atomization of the oil. Therefore, high rates of make-up feed are required.

Steam atomizing burners have oil and air flow characteristics which are similar to return-type mechanical atomizing burners.

In discussing the selection of any control system, prime consideration must be given to certain factors:

(1) The quantity to be controlled.
(2) Measuring means.
(3) Controlling means.
(4) Feedback.

Before the selection of any automatic combustion control system can be made, the quantity being controlled must be given prime consideration. Invariably, a combustion control system is used to control boiler drum pressure, steam header pressure or superheat temperature. The selected system hinges on the quantity to be controlled and the disturbances that can be expected in the quantity to be controlled —the controlled variable.

The measuring means, controlling means and feedback selected in the control system vary with the components that different manufacturers have to offer. A wide assortment of components is offered in the control fields, but most of these are designed to accomplish the same functions. For this reason, it is well to consider the various general types of automatic combustion control systems which are presently engineered and accepted in control work.

The four general classifications of automatic combustion control systems are:

(1) Series-fuel.
(2) Series-air.
(3) Parallel.
(4) Steam flow-air flow.

In a series-fuel system a master steam pressure controller regulates the firing rate of the ship's boilers by directly adjusting fuel flow to the boiler to maintain steam pressure set point. Fuel flow to the boiler is measured, and the measuring device, a fuel flow transmitter, is used to regulate air flow to the boiler in proportion to the fuel flow to maintain combustion efficiency.

A typical, simplified, positioning-type, series-fuel automatic combustion control system is shown in Figure 7. In the illustrated systems in this article, transfer valves and manual signal generators are not incorporated in order to simplify the described system sketches. All of the illustrated systems use compressed air as the transmission medium. A master steam pressure controller is used to sense fluctuations in steam header pressure from a bank of two boilers. This controller transmits a signal that is proportional to the error in steam header pressure set point.

This signal of error in steam header pressure is used to position the oil return control valve and vary the flow of oil to the boiler. A constant oil supply header pressure is maintained by a steam governor valve on the fuel oil service pump. The governor valve senses pressure in the oil supply header and regulates the flow of steam to the turbine of the fuel oil service pump to maintain a pump speed that insures a constant oil supply header pressure.

An orifice is installed in the oil return line from the burners. A fuel flow transmitter is connected across this orifice. The fuel flow transmitter sends a signal of oil flow to the steam turbine governor valve of the forced draft blower. This automatic signal regulates fan speed to supply the boiler registers with an air flow that is proportional to the fuel flow to the burners.

The function of the fuel-air ratio relay that is installed between the fuel flow transmitter and the blower turbine governor valve is to vary the ratio between oil and air. The fuel-air ratio would be employed in case the size of burner sprayer plates was changed or fuel oil, other than navy special, was being burned in the boiler.

Since fuel oil can be relatively easily metered, the series-fuel system has found widespread use aboard ships. One of the main advantages of the series-fuel system is that, since air flow is regulated by a signal of oil flow, the possibility of carrying a high quantity of excess air for combustion for long periods of time is eliminated.

A series-air control system is one in which combustion air flow is regulated by a master steam pressure controller. Combustion air flow across the burner air registers is metered. The metered signal of air flow is used to control the flow of oil for combustion.

A series-air control system, employing feedback, is shown in Figure 8. In the illustrated system each of the ship's boilers is fitted with a master steam pressure controller which senses boiler drum pres-

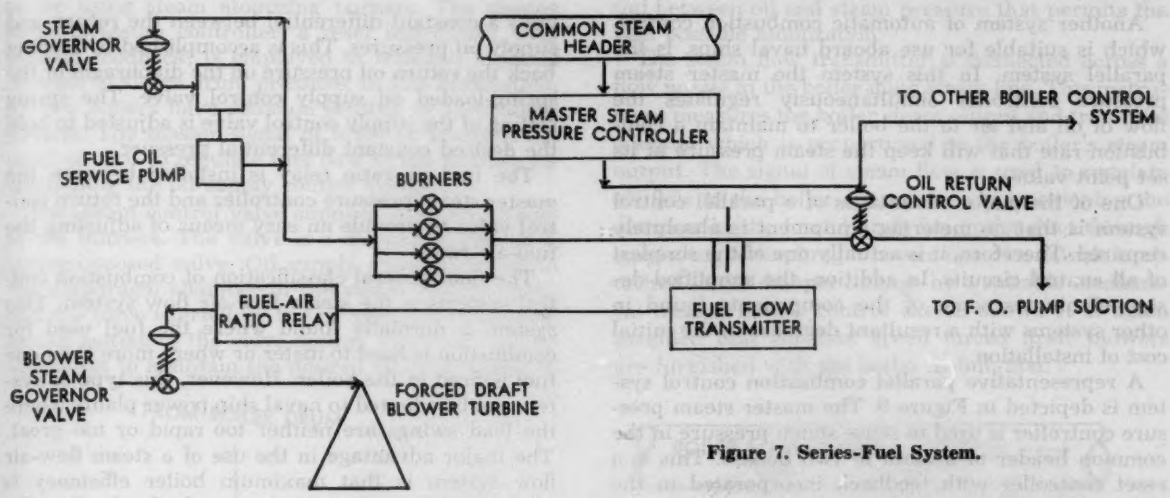

Figure 7. Series-Fuel System.

sure. The master steam pressure controller is equipped with feedback and reset action to maintain steam drum pressure set point regardless of the boiler load.

The master steam pressure signal regulates the flow of combustion air by positioning the forced draft blower outlet damper in conjunction with varying the blower speed. The damper is positioned by a diaphragm power operator; the blower speed is varied by a diaphragm-operated steam governor valve.

The air flow controller is a device which enables air flow to the boiler to be accurately controlled. The air flow controller transmits a signal that is required to maintain a balance between the master steam pressure controller's signal of air demand and the air flow transmitter's signal of actual combustion air flow. The air flow controller is another example of a feedback controller. In this case, the signal of air flow is the feedback element.

The same signal of air flow is transmitted through a fuel-air ratio relay to the supply oil control valve to the boiler's pressure mechanical atomizing burners. In this manner the signal of air flow is used to control oil flow to the burners. As shown in the diagram, the air flow transmitter meters air flow to the boiler by sensing the pressure drop across the air registers through the two sensing taps, windbox and furnace. The transmitter converts this pressure drop across the boiler air registers into a signal of air flow to the boiler.

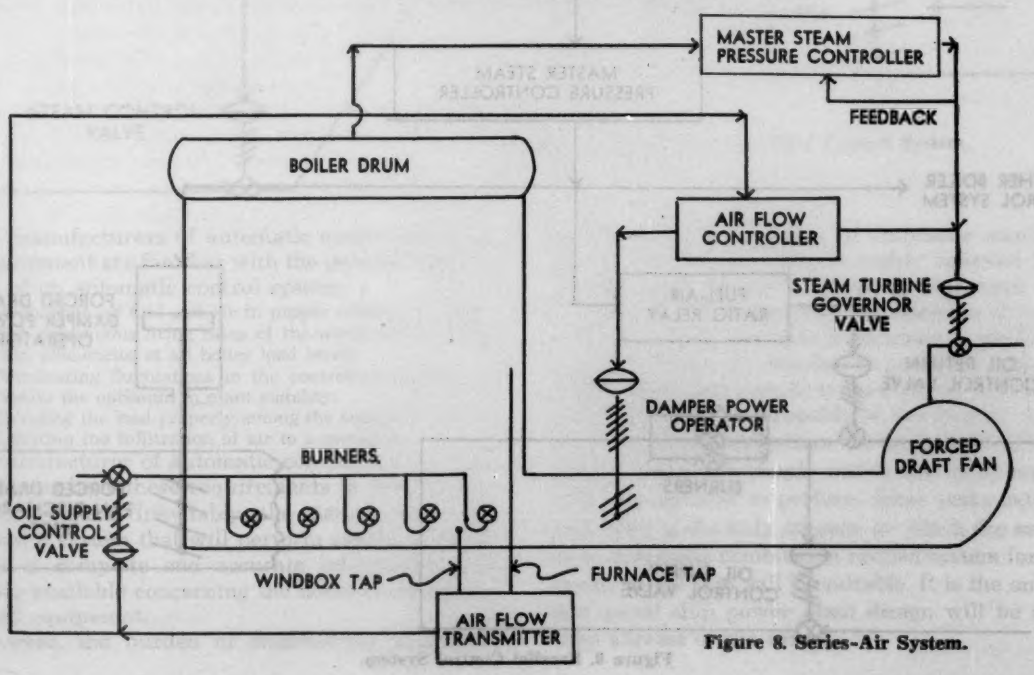

Figure 8. Series-Air System.

Another system of automatic combustion control, which is suitable for use aboard naval ships, is the parallel system. In this system the master steam pressure controller simultaneously regulates the flow of oil and air to the boiler to maintain a combustion rate that will keep the steam pressure at its set point value.

One of the major advantages of a parallel control system is that no metering equipment is absolutely required. Therefore, it is actually one of the simplest of all control circuits. In addition, the simplified design eliminates some of the components found in other systems with a resultant decrease in the initial cost of installation.

A representative parallel combustion control system is depicted in Figure 9. The master steam pressure controller is used to sense steam pressure in the common header of a bank of two boilers. This is a reset controller with feedback incorporated in the design. The master transmits a signal of error in steam header pressure set point. This automatic signal is used to simultaneously regulate air and oil flow to the two boilers.

Air flow is controlled by a pneumatic power cylinder which, through suitable appropriate linkage, positions the dampers in the forced draft blower discharge duct. In this case a constant speed, electric-driven, forced draft fan is one of the boiler auxiliaries.

Oil flow is controlled by a diaphragm-operated control valve in the oil return line. This system maintains a constant differential between the return and supply oil pressures. This is accomplished by feeding back the return oil pressure on the diaphragm of the spring-loaded oil supply control valve. The spring setting of the supply control valve is adjusted to hold the desired constant differential pressure.

The fuel-air ratio relay is installed between the master steam pressure controller and the return control valve to provide an easy means of adjusting the fuel-air ratio.

The final general classification of combustion control systems is the steam flow-air flow system. This system is normally found where the fuel used for combustion is hard to meter or where more than one fuel is fired in the boiler. However, this type of system can be adapted to naval ship power plants where the load swings are neither too rapid or too great. The major advantage in the use of a steam flow-air flow system is that maximum boiler efficiency is maintained even during transient boiler load conditions.

In this system the master steam pressure controller regulates oil flow to the boiler. A steam flow meter, which measures boiler output, transmits a signal of steam flow to regulate air flow to the boiler. Under transient load conditions, both instruments sense the boiler load swings and operate independently to control combustion air and fuel to the boiler to maintain a firing rate that will hold the pressure set point.

Illustrated in Figure 10 is a steam flow-air flow control system that is used in conjunction with a

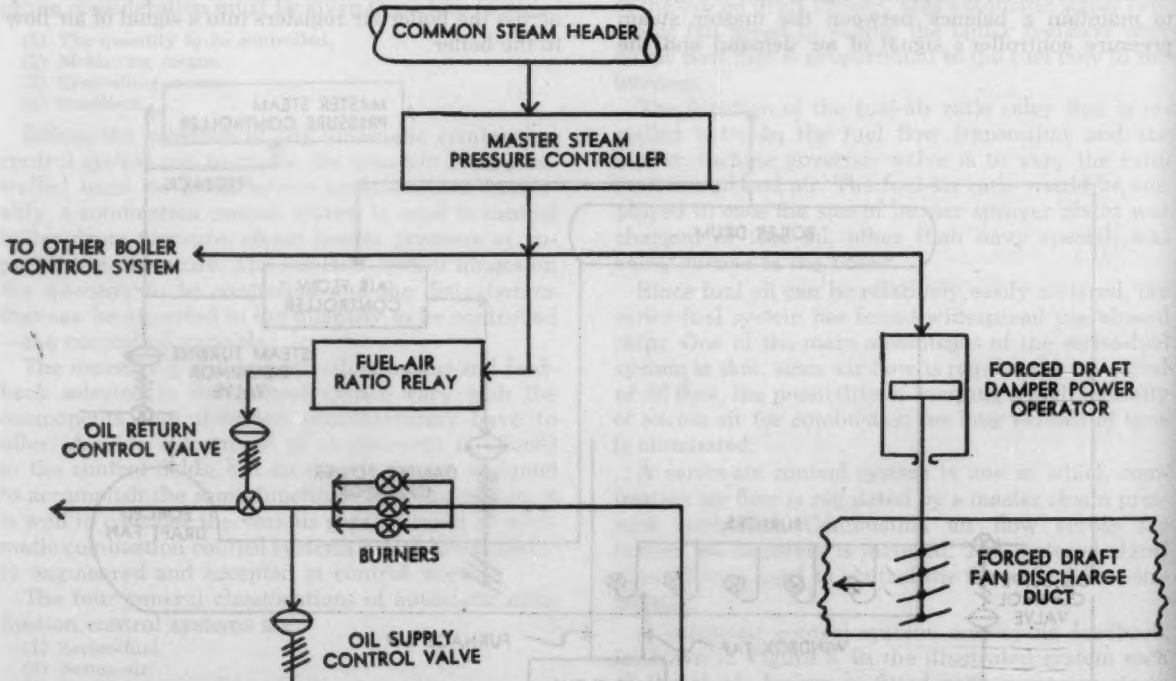

Figure 9. Parallel Control System.

boiler using steam atomizing burners. The master steam pressure controller, a reset instrument with built-in feedback, is employed to transmit a signal of error in steam drum pressure. In this installation, no two boilers have common sensing or controlling devices. The master signal of error in pressure set point is used to regulate fuel flow to the burners by positioning the oil supply control valve.

The steam control valve supplies atomizing steam to the burners. The valve is a diaghragm-operated, spring-opposed valve. Oil supply pressure is fed to the diaphragm chamber of the steam control valve, and the force exerted by the oil pressure is opposed by the setting of the valve spring. Valve spring tension is set to maintain the desired constant differential between oil and steam pressure that permits the best possible atomization.

The steam flow transmitter is connected across a flow nozzle in the boiler main steam line. This instrument measures the boiler steam output and transmits a signal which is proportional to the boiler's steam output. The signal of steam flow is used to regulate air flow to the boiler air registers by positioning the dampers in the forced draft fan outlet duct through employing a diaphragm power operator which is attached to the damper linkage by a suitable mechanical means. In the control sketch shown it is again assumed that constant speed forced draft blowers are furnished with the boiler installation.

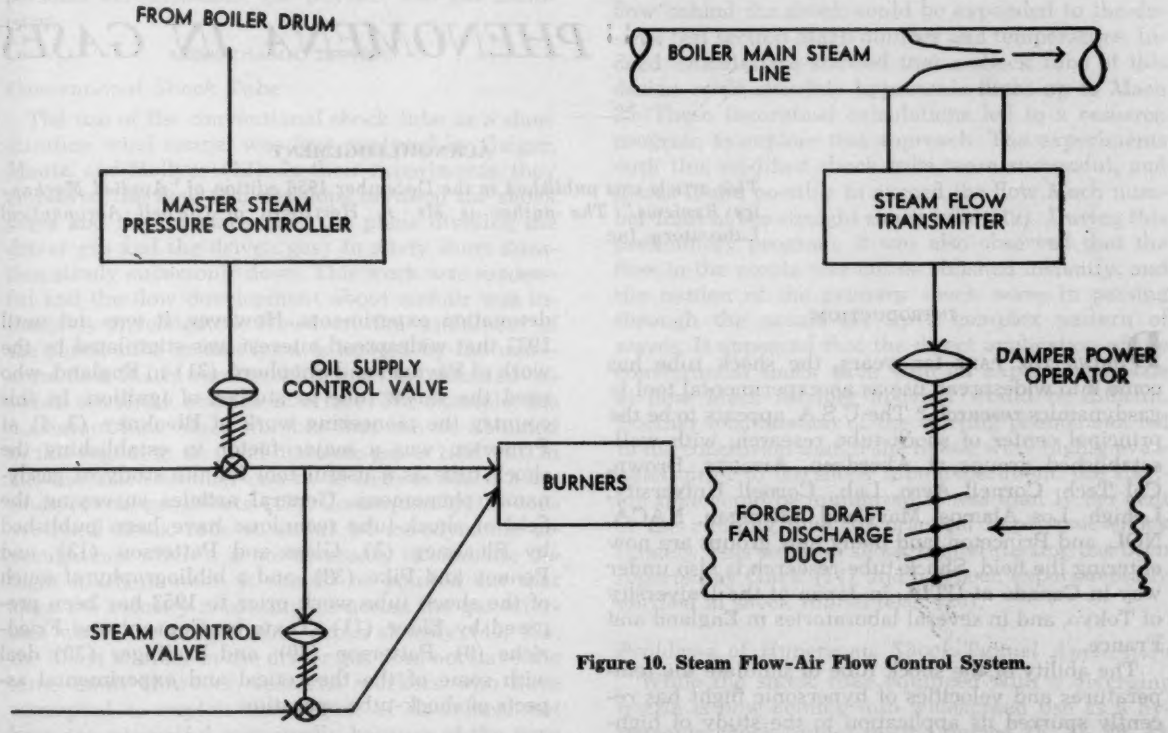

Figure 10. Steam Flow-Air Flow Control System.

The manufacturers of automatic combustion control equipment are familiar with the general requirements of an automatic control system:

(1) Proportioning fuel and air in proper relation to establish continuous firing rates of the maximum combustion efficiencies at all boiler load levels.
(2) Eliminating fluctuations in the controlled variables to obtain the optimum in plant stability.
(3) Dividing the load properly among the boilers in service.
(4) Limiting the infiltration of air to a minimum.

A manufacturer of automatic combustion controls will always bear these requirements in mind in designing a system. Inevitably, the manufacturer can engineer a system that will perform satisfactorily in service if complete and accurate information and data are available concerning the boilers and the associated equipment.

However, the burden of engineering personnel, who deal in the selection of automatic combustion control systems, is not thoroughly relieved by the manufacturer. Naval engineering personnel should be completely familiar with the selection of an automatic control system that is adequate to perform the functions which are peculiar to particular naval ship power plants and specific types of naval boilers. Such personnel should be capable of drawing-up suitable and complete specifications for an individual control system. There are people within the naval organization who are able to perform these tasks extremely well. This is the only manner in which the selection of an automatic combustion control system for a particular naval ship will be suitable. It is the only way that naval ship power plant design will be able to keep abreast of the times.

"APPLIED MECHANICS REVIEWS"

THE APPLICATION OF THE SHOCK TUBE TO THE STUDY OF HIGH TEMPERATURE PHENOMENA IN GASES

ACKNOWLEDGEMENT

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INTRODUCTION

DURING THE PAST ten years, the shock tube has come into widespread use as an experimental tool in gasdynamics research.* The U.S.A. appears to be the principal center of shock-tube research, with well-established groups at Aberdeen, Armour, Brown, Cal Tech, Cornell Aero. Lab., Cornell University, Lehigh, Los Alamos, Maryland, Michigan, NACA, NOL, and Princeton, and many new groups are now entering the field. Shock-tube research is also under way in Canada at UTIA, in Japan at the University of Tokyo, and in several laboratories in England and France.

The ability of the shock tube to simulate the temperatures and velocities of hypersonic flight has recently spurred its application to the study of high-temperature phenomena in gases. This paper will review the application of the shock tube to the study of high-temperature phenomena in gases and discuss some of the more important experiments and investigations that have recently been carried out. In particular, the application of the shock tube and its modified forms will be discussed in connection with the study of hypersonic flight, high-temperature chemical kinetics, and high-temperature gas physics.

HISTORICAL DEVELOPMENT

Early Research

The shock tube was originally devised by Vieille (48) in 1899 when it was used in connection with detonation experiments. However, it was not until 1937 that widespread interest was stimulated by the work of Payman and Shepherd (31) in England, who used the shock tube in studies of ignition. In this country the pioneering work of Bleakney (3, 4) at Princeton was a major factor in establishing the shock tube as a useful tool for the study of gasdynamic phenomena. General articles surveying the field of shock-tube technique have been published by Bleakney (3), Glass and Patterson (13), and Penney and Pike (33), and a bibliography of much of the shock tube work prior to 1953 has been prepared by Elder (11). Texts by Courant and Friedrichs (9), Patterson (30), and Rudinger (39) deal with some of the theoretical and experimental aspects of shock-tube operation.

High-Temperature Studies

Many of the early investigators in gasdynamics observed that very high temperatures could be obtained behind strong shock waves. However, the early shock-tube studies did not exploit this capability. Actually, the early high-temperature experiments were carried out behind shock waves obtained by other techniques; for example, Zeldovich (51, 52) fired high-speed bullets (up to 10,000 fps) into mercury vapor, and Muraour (26, 28) used small explosive charges and studied emission spectra of heated gases. The technique of using explosives in the form of shaped charges and explosive lenses has been highly developed by the Los Alamos group (8, 41), and has been extensively exploited in fundamental research in very strong shock phenomena. (The Los Alamos group has generated shock

* The conventional shock tube consists of a duct separated by a diaphragm into high and low pressure regions. When the diaphragm is ruptured, a plane shock wave is generated which propagates into the low pressure region simultaneously accelerating the gas and raising its temperature.

strengths of well over Mach 200 in air by explosive means.)

The extension of the conventional shock tube to high-temperature research was pioneered by Kantrowitz (18, 34, 35, 36) at Cornell University, who used the shock tube for many original studies of the nature of gases at high temperatures. At approximately the same time, independent work was being carried out by LaPorte's group (23, 46) at Michigan, where an extensive study of the spectral radiation emitted by gases in shock tubes was started.

These successful programs aroused great interest in the further development of shock-tube techniques and, at the present time, the shock tube is widely used as a tool for high-temperature research in hypersonic aerodynamics, gas physics, and gas chemistry.

AERODYNAMIC TESTING

Conventional Shock Tube

The use of the conventional shock tube as a short duration wind tunnel was first explored by Geiger, Mautz, and Hollyer (12). In their experiments, they employed the flow that develops between the shock wave and the interface (i.e., the plane dividing the driver gas and the driven gas) to study short duration steady supersonic flows. This work was successful and the flow development about airfoils was intensively investigated. However, the usefulness of the shock tube in this form is limited by the maximum flow Mach number which can be obtained between the shock and the interface. For example, the maximum flow Mach number that can be obtained in this region in an ideal diatomic gas is 1.89, but, in air, the Mach number can be as high as Mach 3 because of real-gas effects (43). Consequently, the conventional shock tube is useful for aerodynamic investigations when it is not necessary to simulate the flight Mach number. It should be pointed out that since the velocity is continuous across the gas interface while the temperature drops sharply (40, 49), the Mach number in the driver gas does not have the same limit. However, research workers who have attempted to exploit this region of flow have not been too successful, principally because of the very turbulent character of the flow (25). At Cornell Aeronautical Laboratory, it was felt that, if the Mach number limitation in the flow between the shock wave and the interface could be circumvented, the shock tube would prove to be a unique tool for hypersonic research.

At a flight Mach number of approximately 16, the equilibrium stagnation temperature at the nose of an insulated blunt body is approximately 6000° K in air at a density altitude of about 60,000 ft. At this temperature, the thermal energy of the air is sufficient to excite the higher rotational and vibrational states of the diatomic molecules, produce dissociation and ionization, and cause chemical reactions such as the formation of nitric oxide. New problems are consequently introduced since, in this temperature range, the air may be considered a chemically active fluid. For example, the convective heat transfer—the amount of heat transferred through the boundary layer to a body—may depend to a large extent upon the degree of dissociation and recombination inside and outside of the boundary layer. Thus, in this relatively unexplored temperature range, a primary need has been the development of laboratory facilities capable of creating the high temperatures in air which will be encountered in hypersonic flight.

Modified Shock Tube

Theoretical studies at Cornell Aeronautical Laboratory showed that, by terminating the end of the shock tube with a diverging nozzle, the low supersonic Mach number, high stagnation temperature flow behind the shock could be expanded to the desired test section Mach number and temperature. Indeed, calculations showed that a shock tube of this design could simulate hypersonic flight up to Mach 25. These theoretical calculations led to a research program to explore this approach. The experiments with this modified shock tube were successful, and it was found possible to exceed the flow Mach number limit of the straight shock tube (19). During this preliminary program, it was also observed that the flow in the nozzle was not established instantly, and the motion of the primary shock wave in passing through the nozzle set up a complex pattern of waves. It appeared that the direct application of the conventional shock tube with an expanding nozzle at flow Mach number above 7 would be difficult. Further examination of the starting phenomena led to the conclusion that, if the nozzle were highly evacuated prior to the shock tube experiment, the starting time could be minimized to less than 10 per cent of the running time for practical hypersonic shock tunnels. This work on shock tunnel starting has been reported by Glick (14) and has been experimentally verified in shock tunnel tests (20).

Problems of Hypersonic Shock-Tunnel Application

While the shock tube equipped with a diverging nozzle is now coming into widespread use as a hypersonic shock-tunnel testing device (5, 21, 29, 44, 50), there are many problems involved in its use which have severely limited the full realization of its potential. One limitation, of course, is the extremely brief testing times that are available in devices of this type. For example, in the Cornell Aeronautical Laboratory shock tunnel, which has a low-pressure chamber approximately 40 ft. long, the available testing time is less than one half millisecond at Mach 15, allowing for losses.

The brief testing time introduces the question of whether the flow over a model has sufficient time to become fully established. It is believed, based on experimental and theoretical grounds, that the wave pattern and boundary layer reach a steady state in appreciably less than one half millisecond for models approximately six inches long, since this time at

Mach 15 corresponds to approximately fifteen model lengths of flow. However, it is not certain whether the wake flow is fully-developed in the short times available in the hypersonic shock tunnel, and investigations of the establishment of the wake flow are now in progress.

Also, the brief testing times make the problem of instrumentation extremely difficult. However, it has been found (7, 47) that heat-transfer data can be obtained during a run by employing resistance thermometers of special design. It appears (47) that, if a thin metallic film about one-tenth micron thickness is bonded to the surface of a dielectric model, the temperature of the film corresponds to that of the surface with a lag which may be considered small as compared to the testing time. The heat-transfer rate at the surface during a run can be determined from the measured time history of the surface temperature. Techniques of instrumentation for the measurement of forces and pressures on the model in a hypersonic shock tunnel are also being investigated and, at the present time, a three-component balance system is being explored for shock-tunnel work (47).

Instrumentation for the measurement of pressure is being rapidly improved, and it is anticipated that in the near future pressure transducers will be available for use in shock-tunnel tests which should be sufficiently sensitive for the determination of static body pressures and have rise times on the order of microseconds. However, while the techniques of model instrumentation are being rapidly developed, little progress has been made in developing instrumentation for the measurement of the state of the flow in the test section; i.e., the absolute velocity of the flow, its density, and pressure under hypersonic shock-tunnel conditions.

In addition to the problems involved in shock-tube instrumentation, there are other problems which have been uncovered during the development of the hypersonic shock tunnel. Perhaps the most important of these at the present time is the problem of shock attenuation due to viscous forces. If reasonable testing times are to be obtained in shock tunnels, the length-to-diameter ratios of the low-pressure section must be extremely large in practical applications. For example, the Cornell Aeronautical Laboratory shock tunnel has a l/d in the low-pressure section of approximately 250, and any decrease in this value would be inconvenient. However, at these l/d's, the attenuation of strong shock waves becomes appreciable. As an indication of the seriousness of this shock attenuation, it was observed that an initial shock Mach number of approximately 18 attenuated to about 11 at the end of the tube. This attenuation results in a continuous variation in the density and velocity between the shock and interface.

These flow variations were not observed during the initial experimental work when schlieren and luminosity photographs were used as the principle method of nozzle instrumentation. However, when heat-transfer records were taken, it was observed that the heat-transfer rate at the nose of the model showed a variation during the run. Further examination showed that this heat-transfer variation was caused by continuous variation in the flow parameters at the nozzle caused by shock attenuation. Indeed, the heat-transfer gage has proven to be an extremely sensitive probe for shock-tube experiments.

At the present time, considerable attention is being devoted by various research groups to shock attenuation phenomena. Mirels (27), Trimpi and Cohen (45) have offered theories of attenuation in a shock tube, and several groups are now working on experimental verification and extension of these theories. In particular, a study of high Mach number shock attenuation is under way at the NACA under the direction of J. J. Jones. Jones has observed that the higher the speed of sound in the driver, the greater the shock attenuation.* (This result has been confirmed in tests at C.A.L.) Since high driver acoustical velocities are required for driving strong shocks, the application of the shock tunnel at high Mach numbers in slender tubes may be extremely difficult.

It should be pointed out that shock tubes of more sophisticated design may alleviate the attenuation problem. For example, at Cornell Aeronautical Laboratory, a reflected shock technique of operation is now being extensively studied which promises an effective increase of testing time per foot of shock-tube length of nearly 25 times that of the conventional shock tube (21, 22). This technique involves the insertion of a converging-diverging nozzle at the end of the low-pressure chamber and the proper selection of the driver gas. Preliminary experiments at C.A.L. have demonstrated that this technique can be carried out successfully and a program of exploring this modification as a method for relieving the attenuation problem in the shock tube is now under way.

SHOCK-TUBE STUDIES IN CHEMISTRY

The application of the shock tube to the study of high-speed chemical reactions goes back again to the pioneering work of Payman and Shepherd (31, 32). Since then, the use of the shock tube for the study of high-speed chemical reactions has become widespread. While the ability of the shock tube to heat gases to high temperatures is important in chemical studies, it is of only secondary importance when compared to the precision with which the state of the gas can be monitored. Indeed, if the shock velocity is measured, the enthalpy of the gas behind the shock wave may be accurately determined. The time of heating is small and heat losses due to radiation and conduction may be safely neglected. Further, the shock wave processes the gas homogeneously and uniformly so that when the shock tube is used as a chemical reactor, the spatial variation of properties

* In private communication with the author.

in the reacting mixture is small. The absence of gradients facilitates studies using spectroscopy, schlieren and interferometry techniques, as well as gas sampling methods.

The shock tube has also been used in the study of detonation and combustion phenomena in gaseous mixtures, but this work is beyond the scope of this paper.

Applications to Chemical Kinetics

An early application of the shock tube to chemical kinetics was developed by Davidson (6) and his associates at Cal Tech in their studies of dissociation reactions. In these experiments, gases, such as N_2O_4 which is opaque, were dissociated by weak shock waves and the kinetics of the reaction was followed by optically observing the change in gas opacity with time. This technique has been extended by Hornig (10, 16, 17) and his associates at Brown University, where emission and absorption spectroscopy has been employed to study the reacting mixture immediately behind the shock. The appearance of various molecular and atomic species was detected and provided data on the chemical kinetics. At the present time, the combination of the shock tube and spectroscopy is receiving considerable attention from other research groups, and this technique is expected to find a useful application in the field of chemical kinetics.

However, shock-tube spectroscopy is not without its problems. For example, the reaction velocities may be high and the radiation may be of low intensity. It is extremely difficult to obtain useful time-resolved spectra under these conditions. Also, shock-tube spectra are often confused by the presence of impurities. It must be pointed out that, in the application of the shock tube to high-temperature research, impurities are extremely difficult to eliminate and great care must be taken in this phase of the work. The difficulty is caused by the fact that the shock-tube interior must be frequently exposed to the atmosphere and to the severe conditions imposed by the driver which tend to leave impurities in the shock tube.

Another shock-tube modification that obviates some of the problems discussed above is being developed at Cornell Aeronautical Laboratory. In this technique, a conventional shock tube is modified so that the reactant gas sample can be processed by a single, controlled high-temperature pulse. The geometry of the shock tube is so arranged that the reactant gas is first compressed and heated by the primary and reflected shock waves. The reactant gas is then allowed to remain at the reaction temperature and pressure for a specified period of time during which the chemical reaction proceeds. The reactant gas is then suddenly cooled by an expansion wave. If the cooling rate is very high, the reaction rates can be reduced so rapidly that the reaction is "frozen" and the products that exist at the first instant of cooling remain after the run and can be analyzed by examining samples of the gas left in the shock tube. It should be pointed out, however, that this technique is limited to the study of those reactions and products which can be frozen. For example, free radicals which are created at the high-temperature conditions would react very rapidly even after cooling so that their presence could not easily be detected.

A description of the operation of the Cornell Aeronautical Laboratory chemical shock tube may be found in reference 15. This shock tube has been used to study in detail the reaction $N_2 + O_2 \leftrightarrows 2NO$. This reaction, it is interesting to note, is also of importance in hypersonic flight since, at high stagnation temperatures, a considerable amount of nitric oxide may be formed in the vicinity of the body and may remain frozen out after the passage of the body. In the chemical shock tube, it was possible to study the kinetics of nitric oxide formation in the temperature range from 2000°K-3000°K over a wide range of operating pressures. From the observed data, rate constants for the forward and reverse reactions were calculated assuming a bimolecular reaction, which has proven adequate at lower temperatures. It was observed that in the temperature range of 2000°K-3000°K, different reaction rate constants were obtained at a given temperature for different oxygen concentrations. These results indicated that the reaction did not agree with the bimolecular hypothesis. A literature search showed that the chemical shock-tube data agreed very closely with results that Zeldovich obtained in the same temperature range using a combustion bomb (53). Zeldovich proposed a chain mechanism to explain his data. This chain mechanism implies that when the data are reduced assuming the "bimolecular" mechanism, the reaction-rate constants vary inversely with the square root of the oxygen concentration, which is in essential agreement with results of the C.A.L. investigation.

In the Zeldovich chain mechanism hypothesis, it is assumed that oxygen dissociation reaches equilibrium in a time small compared with that for the formation of nitric oxide. Theoretical calculations (1), however, indicate that the relaxation time for oxygen dissociation is far longer than the time for the formation of nitric oxide as determined by this experimental investigation. Thus, the experiments performed in the chemical shock tube suggest that the model employed in these theoretical calculations be re-examined. Additional experimental work, which is described in the next section, indicates that dissociation relaxation times in oxygen are indeed small, and that the assumption of the Zeldovich chain is correct.

SHOCK-TUBE STUDIES IN PHYSICS

The high-temperature potential of the shock tube has given the experimental physicist a simple and convenient tool for appreciably extending the range of study of high-temperature phenomena in gases. It should also be pointed out that, although it is possi-

ble to heat gases to fairly high temperatures by other means, the ability of the shock tube to produce a homogeneous gas sample in a well-defined thermodynamic state is noteworthy. These advantages, which are peculiar to shock-tube techniques, are presently being exploited at many laboratories both in this country and abroad.

The earliest radiation studies in shock tubes were carried out at Cornell University by Kantrowitz (35) and his group, who studied the radiation from argon. These workers were able to observe a second-order Stark effect in argon and study the character of the continuum radiation. Similar studies in argon, krypton, neon, and xenon were carried out at the University of Michigan by LaPorte (46) and his associates. Other shock-tube work by Kantrowitz's group has included conductivity studies (24) and magneto-hydrodynamics experiments.

Shock-tube work has been carried out at Los Alamos by Schreffler and his associates, who have used explosive-driven shock tubes capable of generating strong shock waves. Since the work at Los Alamos has included experiments at shock strengths on order of magnitude above those at other laboratories, several singular phenomena have been observed. For example, the radiation intensity from argon heated by strong shocks is very great and preheats the gas in front of the advancing shock wave, especially near the boundaries. The shock front is therefore distorted by the nonuniform radiation heating of the gas in front of the advancing shock wave (41). Another important related study carried out at Los Alamos (8) was the determination of the dissociation energy of nitrogen by precisely measuring the space-time history of the shock and gas interface.

Vibrational relaxation studies have been carried out at Princeton by Bleakney (2) and his colleagues, and at Naval Ordnance Laboratory (42), using a spark interferometer technique to examine the density gradients behind shock waves moving into oxygen, nitrogen, air, and CO_2. Similar experiments of dissociation relaxation are now in progress. Relaxation studies have also been carried out at the University of Maryland by Resler (37) and his group, who have observed several anomalous relaxation phenomena.

It should be pointed out that the same sort of advantages and disadvantages that apply to aerodynamic and chemical investigations in the shock tube apply to physics studies. Short duration of phenomena, boundary-layer effects, impurities in the gases have challenged the shock-tube experimentalist.

Physics studies at C.A.L. have generally been restricted to studies of the high temperature properties of air and its chief components, oxygen and nitrogen. In addition to the experimental shock-tube program, a theoretical program has been underway for several years to calculate the thermodynamic and transport properties of air, oxygen, and nitrogen up to temperatures of 10,000°K over a wide range of densities.

The first experimental work at C.A.L. was a study of the physics of the flow behind strong shock waves using schlieren optical techniques. The schlieren pictures clearly showed two characteristics of high temperature air. First, at the high temperatures produced behind strong shocks, air does not behave like a gas with a constant heat capacity, but rather, vibration and dissociation become important and contribute to the heat capacity. The increase in the heat capacity of air due to vibration and dissociation appreciably affected the observed flow Mach number. Second, pictures taken with a vertical schlieren knife edge showed a relaxation zone immediately behind the shock, similar to those observed in Bleakney's relaxation studies.

These first studies showed important areas of investigation that could be carried out conveniently in the shock tube. Additional experiments have been under way for some time in which the schlieren technique for studying relaxation has been applied to oxygen and nitrogen. Preliminary results have been obtained in oxygen which show that, in temperature and density ranges where vibrational relaxation is able to be recorded with this technique, there is good agreement with the vibrational data of Blackman (2). However, at higher temperatures, a new relaxation zone has been observed by Glick and Wurster which tentatively has been identified as dissociation relaxation. The measured times of dissociation relaxation for oxygen are, however, orders of magnitude smaller than those predicted in reference (1). The experiments in oxygen are now being repeated with high gas purity. If the preliminary results are verified in these studies, the theoretical mechanism for oxygen dissociation will require further investigation (1, 38).

Another study that is currently being pursued at C.A.L. is the study of radiation from air up to temperatures of 8000°K. Emission spectra of air at temperatures from 6000°K to 8000°K have been taken. These spectrograms show several molecular bands, and the resolving power is sufficient to resolve many of the rotational lines. The spectrograms have not been fully analyzed, but band systems of NO and OH were clearly visible from shock-heated room air. It is interesting to note that the CN band, which has plagued shock-tube spectroscopy in the past, did *not* appear when a sufficient purity was achieved. In addition to the emission studies, absorption studies of air are planned for the future.

CONCLUSIONS

The shock tube has developed, during the past ten years, into a powerful tool for the study of high-temperature phenomena in gases. The experimental technique is rapidly advancing and it is expected that the shock tube will find increasing applications in the field of hypersonic flight, high-temperature chemical kinetics, and high-temperature gas physics.

1. *Hypersonic Flow Research*

The conventional shock tube is capable of producing air temperatures which are high enough to cover the range of hypersonic flight up to a Mach number of 25. However, in order to simulate both the high temperatures of hypersonic flight and the high flow Mach numbers, the conventional shock tube must be modified. The most successful modification, at the present time, has been the addition of a diverging nozzle to the downstream end of the low-pressure chamber to increase the flow Mach number. While this modification has proven successful for many flow research problems, the extremely brief testing times possible at high Mach numbers (approximately one-half millisecond) introduce the problem of flow establishment and complicate the problem of instrumentation. Also, the quest for longer testing times requires the use of relatively long shock tubes and introduces the problem of severe shock attenuation. New modifications of the shock tube are now being proposed and explored which promise to alleviate this attenuation problem and extend the range of shock-tube operation.

2. *Application of the Shock Tube to Chemistry*

Shock-tube spectroscopy has been successfully applied to the study of high-speed chemical kinetics.

A modified form of the shock tube has been developed which generates a single, high-temperature pulse. This technique brings the gas to the reaction temperature suddenly, maintains the reaction conditions for a fixed period of time, and then rapidly cools the reacting gas. Reactions that can be frozen by the sudden quenching available in this shock-tube modification can be studied in detail. In particular, the reaction of $N_2 + O_2 \leftrightarrows 2NO$ has been studied, and the data have been correlated with a chain mechanism.

3. *Application of the Shock Tube to Physics*

The high-energy shock tube brings the physics of high-temperature gas phenomena a new research tool with which to study gases under known conditions at high temperatures.

The shock tube in this form has been, and is now being, actively applied to the measurement of the equation of state of gases, the study of atomic and molecular spectra, the measurement of electrical conductivity, and the kinetics of the establishment of thermal equilibrium. In particular, a great deal of attention is now being devoted to the measurement of relaxation times to dissociation for oxygen and nitrogen. Preliminary experiments have shown extremely brief relaxation times for dissociation in oxygen.

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Power loss from piston knock may be largely overcome in internal combustion engines through scientific study being carried on with the shock tube. The shock tube is being used as a device for producing air-fuel explosions that can be photographed, in order to study just what causes different fuels to give good or poor performance.

"U. S. NAVAL INSTITUTE PROCEEDINGS"

NAVAL CONSTRUCTION ON THE GREAT LAKES

ACKNOWLEDGEMENT

Captain Marvin H. Gluntz, USN, is the author of this article, reprinted from the February 1957 issue of "U.S. Naval Intitute Proceedings." Copyright 1957 by U.S. Naval Institute.

THE STORY of naval construction on the Great Lakes is more than the detailing and interpreting of statistics. It is more than numbers of ships built and their tonnages. It is the story of Presque Isle, of shipbuilding "firsts," of short, narrow locks and shallow channels limiting access to and from the sea. Above all, it is the story of ingenious and able men. It is all of these and much more!

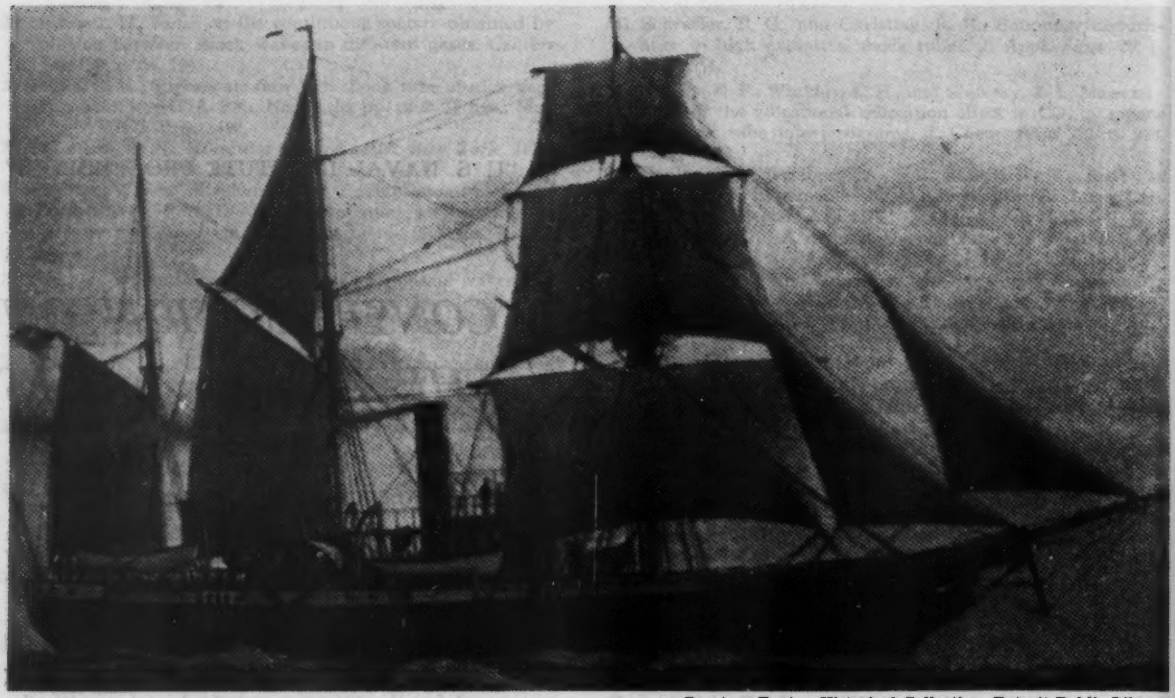
The story started with the sloop *Detroit*, which our government bought in 1796 to carry troops and supplies between Presque Isle (Erie, Pennsylvania) and other ports in the Old Northwest. She had been built three years earlier by Jim Connoly and Captain Peter Curry, who were early residents on the River Rouge. The acquisition of the 70-ton *Detroit*, the first United States government vessel on the Lakes, brought Captain Curry into government service as her skipper. Although he had three years' experience in operating the vessel in the fur and general merchandise trade, Curry at times had difficulty in securing enough sailors to man all of the vessel's positions. It seems that sailors were then "... few and in big demand." This shortage was met by detailing soldiers to the unfilled jobs and by paying them an extra $5 per month in addition to their regular $4 monthly salary. Even so, the soldiers could not match the $20 per month paid to sawyers, the $15 paid to teamsters, or the $45 (plus two rations) paid to ship carpenters.

These were the prevailing wages in 1797, when our first shipyard on the Great Lakes was established just below Detroit on the River Rouge. This yard was short lived, but it succeeded in turning out two warships—the 150-ton brig *Adams* in the spring of 1800 and the 70-ton sloop *Tracy*. Both vessels immediately began carrying supplies and personnel for the government. In keeping with the spirit of the times, they occasionally carried some commercial freight as well. The resulting revenues helped reduce their annual operating costs substantially.

A highlight in the career of the *Tracy* occurred in 1803, when she carried a garrison to what is now Chicago. By that act she became closely associated with the founding of the Windy City. Existing records do not record further incidents in the life of the *Tracy*, but they do record the capture of the *Adams* by the British, along with the fall of the settlement at Detroit in August of 1812. They also tell us that British gunfire sank the *Adams* a little later in order to prevent her being recaptured by a group of Americans under the daring leadership of Lieutenant Elliott, a U. S. naval officer.

It would be interesting to have a record of all the vessels built and operating on the Lakes during the 1790's, but the sources of information are meager. Our lack of records apparently stems from a fire which took place in several offices in the War Department in the year of 1800, destroying valuable papers that covered the period. From other references, however, we know that there was considerable shipbuilding activity on the River Rouge. For example, Captain Hector McLean, Commandant of Fort Malden at Amherstburg, complained by letter, dated July 10, 1799, to his superiors at Quebec that he could not get hull repairs effected on His Majesty's Ship *Ottawa* because of the number of vessels being built at the "River Rouge yard where the wages are high."

At the turn of the century there were only two



Courtesy Burton Historical Collection, Detroit Public Library

USS MICHIGAN—A LONG-LIVED VETERAN OF SERVICE ON THE GREAT LAKES

The Navy's first iron-hulled warship, the *Michigan*, was launched at Erie, Pennsylvania, in 1943. She was not stricken from the Navy list until 1943.

United States naval vessels on the Lakes, but twelve years later the number had grown to 37 built or building, and 34 operating. The majority of these warships were schooners mounting less than seven guns and displacing less than a hundred tons apiece. Eleven of the vessels, however, carried batteries in excess of 18 guns and displaced more than 450 tons each. The largest warship operating on the Lakes was the *Superior*, 1,580 tons and 62 guns. She was attached to the Lake Ontario fleet and later became Commodore Isaac Chauncey's flagship. The two most famous vessels—and the largest ones on Lake Erie—were, of course, Commodore Oliver Hazard Perry's *Lawrence* and *Niagara*.

Two-thirds of all the warships on the Lakes were stationed on Lake Ontario, since we needed to counter the vigorous shipbuilding efforts of the British commander stationed there. Lake Erie, with only a third of the vessels on the Lakes, provided the setting for Commodore Perry's brilliant naval victory at Put-in-Bay in September, 1813. Most Americans could give the highlights of that victory, but not too many are familiar with the job the people of Presque Isle, under the outstanding leadership of Daniel Dobbins, did in building Perry's fleet in such record-breaking time.

Dobbins' letters and papers on file with the Buffalo Historical Society give us a detailed description of that job and of that remarkable leader. They tell us that Dobbins was skipper of the two-masted topsail trading schooner *Salina* at the time he was captured by the British at Mackinac in July, 1812. He was taken to Detroit and then to Malden, where he escaped a month later by paddling a dugout across Lake Erie to Sandusky. There he procured a horse and rode to Cleveland. Proceeding by canoe to Presque Isle, he gave the first news of the fall of Mackinac and of General Hull's surrender of Detroit. At the request of General Mead, the officer in command of Presque Isle, Captain Dobbins at once started for Washington as bearer of dispatches giving details of the important events which he had witnessed. The journey was long and toilsome, through the forests to Pittsburgh, thence by the military road to Baltimore.

Upon reaching Washington, Dobbins hastened to the War Office and laid his dispatches before Secretary Eustis. Up to that time not the slightest intimation of the disaster had been received in the capital. The Secretary of War went at once to the White House to confer with President Madison. The cabinet was hastily summoned, and the news was fully discussed. The intelligence of the double disaster was a crushing blow. It seemed as though our empire in the Northwest was gone and the New York frontier appeared to be in greater jeopardy than ever before. Finally, President Madison ex-

claimed: "There is one thing to be done. We must gain control of the Lakes. Therein lies our only safety."

It was decided to place Captain Dobbins in charge of the preliminary work of constructing a fleet on the Lakes. He was commissioned an officer in the Navy and authorized to employ men, purchase supplies, and perform such other duties as might be required to carry out his mission. On his return trip to Erie he engaged several ship carpenters in New York, and they provided the nucleus of his working force.

Dobbins was authorized to draw on the Navy Department for $2,000 to start the building of Perry's fleet, and one of his first steps was to make contracts for standing timber convenient to the shipyard. The uniform price was one dollar a tree. Coal was hauled from the pits—location uncertain—at 6¼ cents a bushel. Wages ranged from $2.50 a day for the master shipbuilder down to 62½ cents for axemen. Hauling, with horses or oxen, cost $4 a day. Board for the men was $2.25 per week.

Acting largely on his own responsibility, but as he believed with the approval of the Navy Department, Dobbins hastened the preliminary work. In order to set a good example, he himself on October 24, 1812, felled the first tree, a great oak, and hewed out the trunk. It afterwards formed the keel of the *Niagara*. At the beginning of November, he engaged Ebenezer Crosby of Buffalo as master builder. Their original contract, still preserved, is one of the many interesting documents in the Dobbins papers.

On December 12, Dobbins wrote a progress report to Secretary of the Navy Paul Hamilton. He told the Secretary that some of the men who were hired in the East had not yet "come on as was expected . . ." and reported, "ice was forming in the Lakes and would soon form a complete barrier against the British for this winter." He declared that he was having difficulty in making contracts with the local interests because, "the people of this country are poor and very liable to fail." Nevertheless, Dobbins stated that he had laid down two hulls of "50-foot keels, 17 foot beams, 5 foot hold and from appearances will be fast sailors if you wish me to go on with this work you will please give me orders to draw, I have expended a considerable sum more than the two thousand dollars on account."

There is nothing among the Dobbins papers which may be regarded as total accounting of the cost of building the fleet. From the accounts of Noah Brown, whom Dobbins selected as Superintendent of Construction, we learn that a total of $19,466.42 was spent during the period from November 1, 1812 to March 27, 1813. This amount included the costs of cutting timber, meeting shipyard payrolls, board for the men, and boating and handling from Buffalo. In these old accounts there is also frequent mention of whiskey—a cost of shipbuilding as commonplace in those days as the weekly board bill.

Dobbins' pleas for additional funds must have been granted because we find him starting construction of the *Lawrence* and *Niagara* early in 1813. Designed by Henry Eckford, the most famous American naval architect of his day, they were 110 feet between perpendiculars, brig-rigged, and armed with eighteen 32-pound carronades and two 12-pound guns.

Iron had to come from Pittsburgh, fitting-out items from Philadelphia, and guns from Buffalo. But even with those obstacles, by July 25—six months from keel date—both vessels were ready for operations, except that they could be only partially manned. Less than two months later, Perry sent his historic message, "We have met the enemy and they are ours."

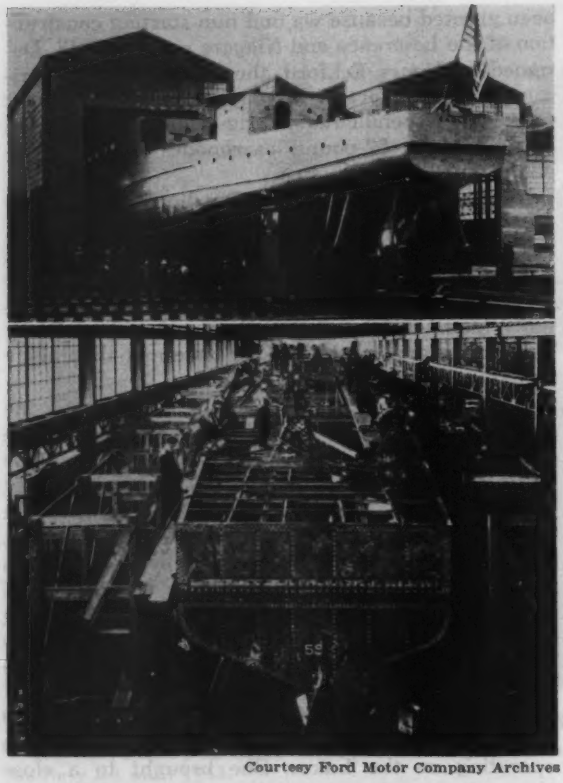
Perry's victory exerted a major influence on the outcome of the war and a decisive influence on the course of naval construction on the Lakes. The Rush-Bagot Treaty signed in 1817 stipulated amongst other things that thenceforth neither party could maintain more than one warship on Lake Ontario, nor more than two on the upper Lakes. The vessels could not exceed 100 tons, and they could not be armed with more than one 18-pounder.* In keeping with the spirit behind the treaty, a United States Navy inspection party in 1821 condemned all but one of the many warships that we had on the Lakes. As a result, the *Lady of the Lake*, a schooner of 89 tons, became in 1823 the only armed American ship operating on the Lakes. She brought to a close the earliest and perhaps the most colorful period of naval construction in that area.

In spite of the original 100-ton displacement limitation of the Rush-Bagot Treaty, we managed to launch the 685-ton *Michigan* at Erie, Pennsylvania, in 1843. She was the Navy's first iron-hulled warship. Her plates were fabricated in Pittsburgh and hauled to Erie by canal and ox teams. Originally rigged as a bark but later changed to a schooner, the *Michigan* also had two inclined, direct-acting, condensing engines which could give her a speed of 10 knots under power. In 1844, she began cruising the Great Lakes, but with only one of the six guns her plans called for. This change was made to meet the ordnance limitation of the Rush-Bagot Treaty and to satisfy the British Minister.

In 1905, the *Michigan's* name was changed to *Wolverine*, so that her old name could be given to a new battleship. The venerable ship made her last trip under power in 1923 and was finally laid up at Erie. In 1943, 100 years after launching, she was stricken from the Navy list and in 1949 she was scrapped. That long life is characteristic of Great Lakes vessels and creates a problem that will be considered later on in this article.

The last half of the nineteenth century saw naval shipbuilding activity on the Lakes at a standstill. From the War of 1812 up to the time of World War I, Great Lakes builders were credited with

* Since 1939, these stipulations have been revised by a series of notes between the U. S. Government and the Canadian Government.



Courtesy Ford Motor Company Archives

ASSEMBLY LINE TECHNIQUES TURNED OUT THE WORLD WAR I EAGLE BOATS

Henry Ford applied his experience in automobile manufacturing to the mass production of Eagle boats. Three assembly lines of seven stations each enabled Ford to make the best use of a limited supply of skilled shipyard workers.

producing just one warship, the aforementioned *Michigan*, while the coastal builders produced over 1,500,000 tons. However, this same period saw a tremendous increase of activity in the building of merchant ships, with the output coming to over 5,300,000 gross tons on the Great Lakes alone.

The rivers in the Great Lakes domain were also producing merchant ships. If their 2,000,000 tons are added to the Lakes output, we find that the Great Lakes Trading Area can take credit—thanks largely to the steel industry's dependence on water transportation—for producing about one-third of the country's entire merchant ship construction up to the start of World War I.

Although merchant ship construction on the Lakes and rivers declined drastically during World War II, naval construction took up any excess capacity as rapidly as it developed.

The drop in merchant ship construction resulted from the inability of inland shipbuilders to deliver big ships through the restrictive locks and channels leading to the sea, but the inland builders were not prevented from constructing and delivering many of the smaller, urgently needed types of naval vessels. They attacked this task with vigor and with the help of assembly line techniques which Henry Ford proved during World War I could be successfully applied to ship construction.

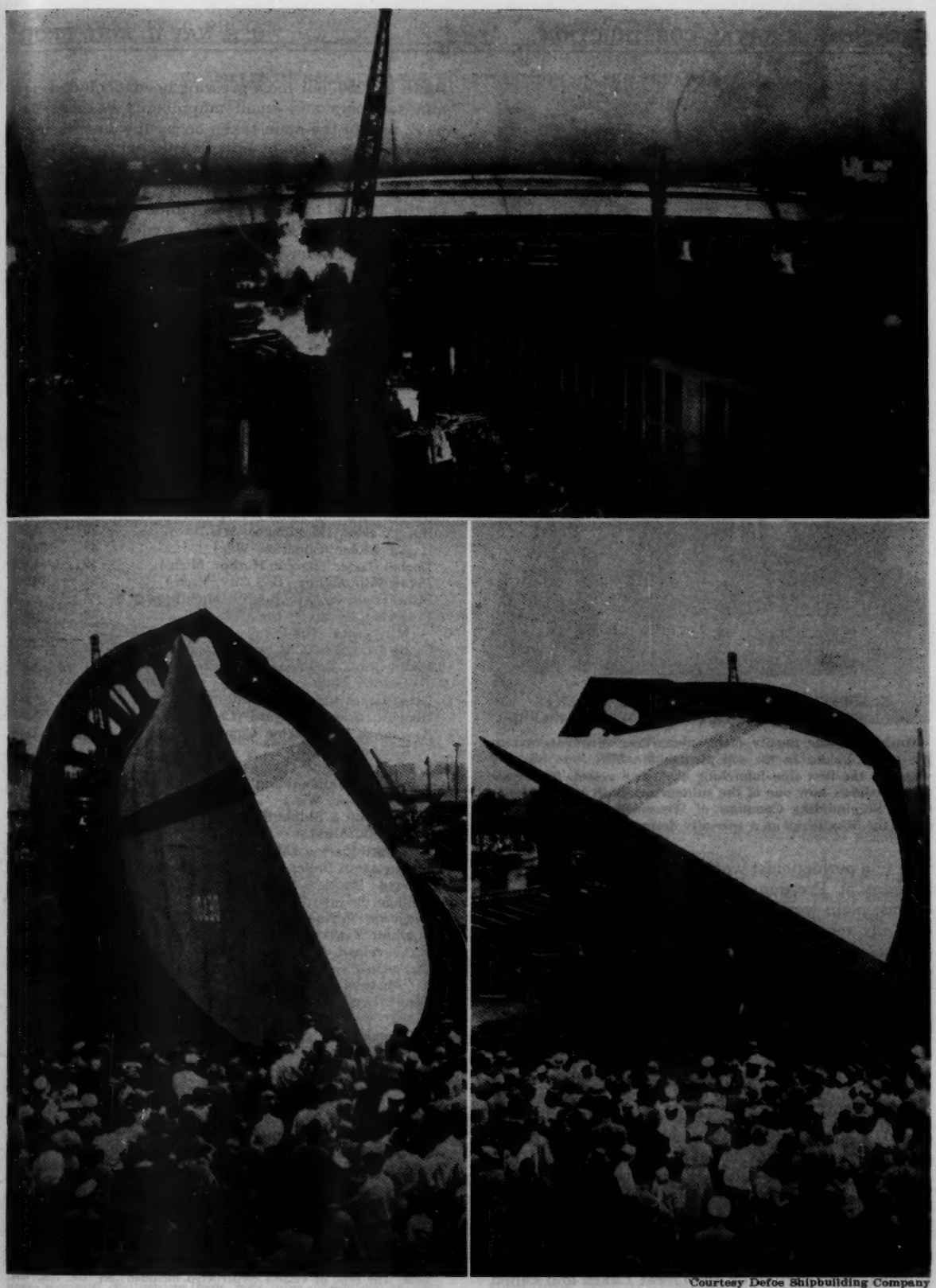
During that war Ford mass-produced 55 Eagle Boats on the Rouge. Applying his car-manufacturing experience, he set up three assembly lines of seven stations each; through them three hulls proceeded simultaneously. In this endeavor Ford proved the feasibility of transferring hulls almost at will from location to location within a fabricating and assembly area. He showed that through simplified ship designs, jigged assemblies, and other forms of standardization in repeat production, the industry could stretch to the utmost the services of the relatively few fully-trained shipfitters, boilermakers, and coppersmiths, and could make maximum use of unskilled labor.

The Ford idea was aggressively exploited during World War II. Inland builders led the parade. Shipyards emerged in the midst of waterfront farm lands on which crops were still under cultivation. On several of these sites, corn was being harvested on one side of a hastily-erected shipyard fence while LST's and other hulls on the inside began to hit the water at a rate which forecast defeat for the Axis powers.

By the war's end, thirty Great Lakes shipbuilders had turned out forty-seven different types of naval vessels totaling 600,000 tons. Included in these types were submarines, destroyer escorts, minesweepers, LST's, and cargo vessels, as well as various amphibious, harbor, and patrol craft. At the same time, eleven builders located along the Mississippi, Missouri, Ohio, and Illinois Rivers had delivered eight different types (above 100 tons each) of naval vessels totaling 900,000 tons. They included small oilers, LST's and LCT's, towboats, and several types of cargo barges.

Having summarized the history of ship construction on the Great Lakes, it is now possible to discuss in some detail the current problems of the Lakes shipbuilders. From 1900 to 1909, nearly 45 per cent of all United States merchant ship tonnage was being turned out by them. Then came a decline which was not halted until World War II, and only recently has the peacetime picture begun to brighten. The reasons for the extent of the decline are not altogether clear. Obviously the two World Wars and the depressions contributed substantially to the total decline. We can also surmise, however, that the product was too good—built to last a long, long time. Could it be too long? Quality has always been uppermost in the shipbuilding industry. After all, safety of life and limb—even the fate of a battle—can hinge on the quality aspects of a vessel and its performance. But is it profitable to have a *Michigan* last 100 years while reaching obsolescence in just a fraction of that time?

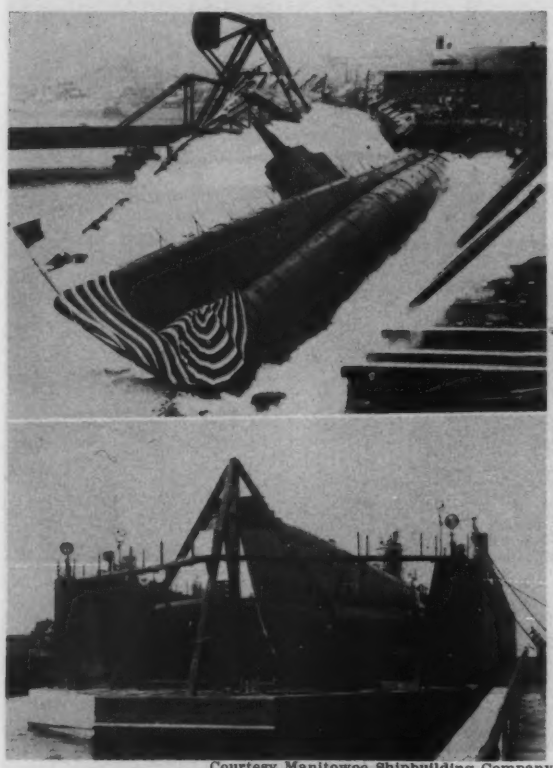
Back in 1813, Noah Brown offered some good ad-



Courtesy Defoe Shipbuilding Company

WORLD WAR II DE'S LITERALLY ROLLED OFF THE GREAT LAKES PRODUCTION LINE

Welding hulls in an upside-down position speeded up construction time. The "turn-over" trunnions, shown above, were developed by Mr. Harry Defoe and illustrate the ingenuity that Great Lakes shipbuilders have displayed in solving their problems.



Courtesy Manitowoc Shipbuilding Company

SUBMARINES BUILT ON THE GREAT LAKES JOURNEYED TO THE SEA DURING WORLD WAR II

During the war, twenty-eight submarines were launched on the Great Lakes. In the top picture the USS *Peto* hits the water in the first side-launching of such a vessel. The lower picture shows how one of the submarines built by the Manitowoc Shipbuilding Company of Wisconsin was transported down the Mississippi on a specially designed floating drydock.

vice to a perfectionist working on the *Lawrence* and *Niagara* at Presque Isle. He said: "We want no extras; plain work, plain work is all we want. They are only required for one battle; if we win, that is all that will be wanted of them. If the enemy is victorious, the work is good enough to be captured."

Brown was not advocating slipshod work but was cautioning against "gilding the lily." Can we today afford to gild the lily when technological changes are coming so rapidly that new vessels are likely to be white elephants fifteen years hence? Can we afford the luxury of 100-year hulls? Should we not enlist the aid of value engineering to help guard against such costly luxury? The Navy's Bureau of Ships has taken positive action in this direction, and the results are encouraging, considering the newness of the program and the small number of full-time value engineers employed.

What is the current status of Great Lakes shipbuilding? The Korean conflict gave a new impetus to naval construction on the Great Lakes and called attention once again to its limitations as well as to its potentialities. When the North Koreans started south in 1950, our most pressing needs included new minesweepers and small amphibious vessels. This work was in the main taken on by the smaller shipbuilders around the country. Although there was a large number of vessels under contract, their individual and total tonnage was comparatively small. Of the 880,000 tons built and building in the United States between 1950 and 1956, some twenty Great Lakes builders have accounted for 67,000 tons, including various types of vessels and small craft. The latter were built for the various services—Navy, Army, and Air Force—under the Navy's supervision in accordance with the Single Service Procurement Program.

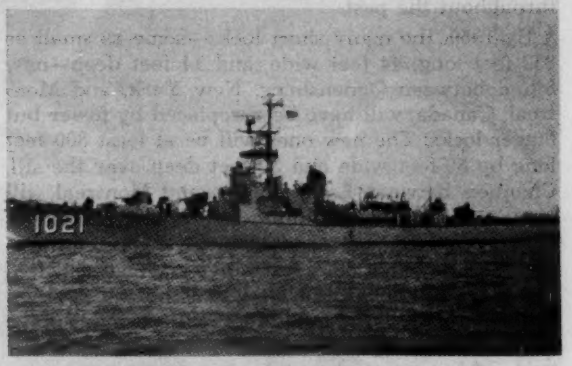
TABLE I—GREAT LAKES NAVAL CONSTRUCTION DURING WORLD WAR II PERIOD

	Vessels No.	Tonnage (Approx.)
Builders with Vessels 100 Tons or Over		
American Cruiser (Detroit, Mich.)	10	1,000
American Ship Building (Cleveland & Lorain, Ohio)	65	53,000
Barnes (Duluth, Minn.)	38	95,000
Burger Boat (Manitowoc, Wis.)	20	6,500
Butler Globe (Superior, Wis.)	47	92,000
Dachel Carter (Benton Harbor, Mich.)	19	7,300
Defoe Shipbuilding (Bay City, Mich.)	154	70,000
Fisher Boat Works (Detroit, Mich.)	3	330
Froeming Brothers, Inc. (Milwaukee, Wis.)	18	23,400
Globe Iron Works (Cleveland, Ohio)	1	800
Great Lakes Engineering Works (Detroit, Mich.)	1	1,500
Great Lakes Industries (Duluth, Minn.)	5	600
Henry C. Grebe Shipyard (Chicago, Ill.)	29	8,500
Kewaunee Engineering Company (Kewaunee, Wis.)	2	1,000
Leathem D. Smith (Sturgeon Bay, Wis.)	90	91,000
Manitowoc Shipbuilding (Manitowoc, Wis.)	79	63,000
Marine Iron & Shipbuilding (Duluth, Minn.)	11	5,200
Marinette Marine (Marinette, Wis.)	5	3,100
Northeastern Boiler (Green Bay, Wis.)	3	300
Peterson Builders (Sturgeon Bay, Wis.)	17	1,700
Pullman Standard (Chicago, Ill.)	34	20,500
Robinson Marine (St. Joseph, Mich.)	8	800
Stadium Yacht Basin (Cleveland, Ohio)	2	500
Sturgeon Bay Shipbuilding & DD (Sturgeon Bay, Wis.)	4	2,000
Zenith Dredge (Duluth, Minn.)	13	6,400
Totals	678	555,000
Builders with Vessels Less than 100 Tons		
Bay City Boats (Bay City, Mich.)	1	60
Burger Boat (Manitowoc, Wis.)	2	180
Chris Craft (Algonac, Mich.)	13,460	141,000
Fisher Boat Works (Detroit, Mich.)	18	1,400
Great Lakes Boat Building (Chicago, Ill.)	2	120
Henry C. Grebe (Chicago, Ill.)	10	1,300
Matthews Company (Port Clinton, Ohio)	2	80
Victory Shipbuilding (Holland, Mich.)	6	630
Totals	13,510	145,000

Note: The type of vessels constructed included: SS, DE, AK, AM, AG, AN, AP, LCU, LCVP, ATR, PCE, PF, PG, YD, YW and many other variations of the foregoing. In addition, seven Great Lakes Builders produced 306 craft for the Army and Coast Guard totaling about 39,000 tons.

EXAMPLES OF RECENT NAVAL CONSTRUCTION ON THE GREAT LAKES

MSO-512 is representative of the latest type minesweepers built by several Great Lakes shipyards.



DE-1021, built by Defoe Shipbuilding Company, Bay City, Michigan, is shown on trials in Lake Huron in July, 1956.

MSB-23 is an example of technological innovation in Great Lakes shipbuilding. Completed in July, 1956, this 56-foot craft is believed to be the largest boat built of plastic up to that time.

LST-1169 was one of several such vessels completed by the Christy Corporation, Sturgeon Bay, Wisconsin, during 1953-1955.

After getting those smaller vessels under way, the Navy shifted its emphasis to *Forrestal*-type carriers, *Nautilus*-type submarines, missile-firing ships, and various other prototype vessels, as well as to the modernization of existing combatant ships. In this phase, fewer but heavier vessels are being worked on; spectacular technological advances like the nuclear power plant, the angled-deck aircraft carrier, the guided missile, the use of increased steam temperatures and pressures, the application of plastics in small boat construction, fittings, and components, the lamination of wood structural members, and phenomenal advances in electronics are being made with breath-taking speed.

The Great Lakes builders have contributed to this technological revolution. The Defoe Shipbuilding Company has made a major contribution to the art of plastic boat construction. In June, 1956, this company finished a 56-foot MSB which, at the time of award and even up to 1956, was the largest known plastic boat ever attempted. During the past two to four years, plastic dinghies have been produced for the Navy at Toledo, Ohio, while in Manitowoc and Sturgeon Bay, Wisconsin, shipbuilders have become proficient in laminating wooden structural members for our various minesweepers.

Nevertheless, the tonnage of Great Lakes naval shipbuilding relative to total United States production during the period of 1951 to 1956 has been relatively small—about 5 per cent. At least two important factors help to account for this situation. One has been the reluctance on the part of some of the larger Great Lakes shipbuilders, who were experiencing a revival of merchant ship construction, to compete for Navy contracts during the early months of the Korean conflict. The other factor boils down again to those old familiar obstacles—locks and channels leading to the sea being too short and narrow for many of our combatant and large auxiliary vessels. Nevertheless, the percentage of combatant vessel construction relative to total naval construction has steadily increased on the Lakes for the whole period between World War I and the present. More and varied naval silhouettes will be seen framed against our Great Lakes horizons as this trend continues, and it is bound to continue because we are doing something now to eliminate, or at least reduce, the restrictive influence of the navigational bottlenecks

which have plagued our Great Lakes shipbuilders throughout the past.

By 1959, the many short locks—some as small as 252 feet long, 44 feet wide, and 14 feet deep—now found between Ogdensburg, New York, and Montreal, Canada, will have been replaced by fewer but bigger locks. The new ones will be at least 800 feet long by 80 feet wide and 30 feet deep over the sill. Channels between Lake Ontario and Montreal will be deepened to 27 feet minimum and several bridges will be replaced or modified to give greater masthead clearance.* Some restrictive navigational features will still be with us after 1959, but the position of the Great Lakes shipbuilder will certainly have been greatly improved for the delivery of many types of larger naval vessels.

In October, 1954, the Chief of the Bureau of Ships recommended to the Chief of Naval Operations that the depth of the entire waterway outside the locks be at least 32 feet in lieu of 27 feet, that the locks have a width of at least 100 feet in lieu of 80 feet, and that bridge vertical clearance be at least 140 feet in lieu of 120 feet. He stated that these increases would expand substantially the shipbuilding, ship repair, and water transportation capabilities of the Great Lakes area, particularly in event of mobilization. Specifically, such changes would permit the transit of vessels otherwise excluded, generally expedite the movement of vessels, and reduce the likelihood of damage to vessels in transit. Other activities are also on record as favoring even larger dimensions. The Detroit Chamber of Commerce, for example, in late 1954 advocated 35-foot depths. Regardless of the dimensions finally reached, the improvements being made right now are so substantial that we could probably use a breathing spell before going on to new achievements.

The Great Lakes shipbuilder is soberly aware of the fact that when the new seaway is opened, his own competitive strength rather than navigational obstacles will determine his naval construction workload. He realizes that his plant may need some refurbishing. His shears, his milling and boring machines, his rolls and brakes, his drills, and his overhead and mobile cranes may need to be reappraised with respect to thicker shell plating, to STS armor, to subassembly weights, and other heavier and larger construction materials. In addition to this physical refurbishing, he wonders how much his know-how with ordnance equipment, with electronics, and, yes, with nuclear power plants needs to be increased.

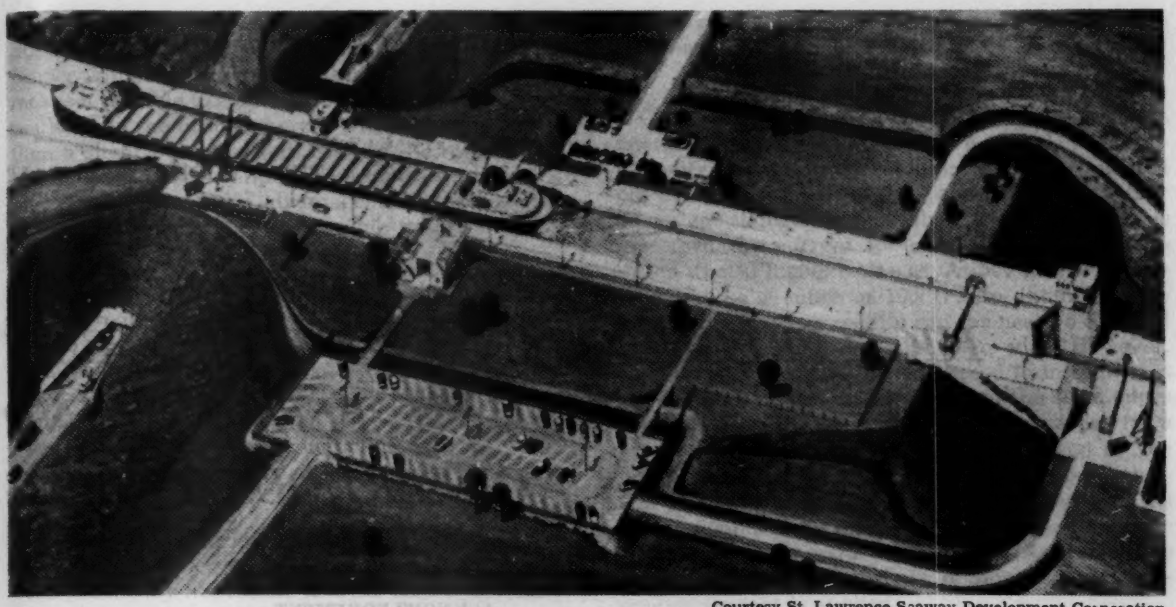
Our Great Lakes shipbuilder also finds his position improved because he sees additional navigational projects encountering less and less opposition.

* When the program is completed, the controlling navigational features along the 2,300 mile route from Chicago to Duluth to the sea will be:
a. Depth—1. From Chicago or Duluth 25'. (Upbound to Chicago or Duluth 21'.) 2. To and from Lake Erie 27'.
b. Width 80'.
c. Length 800'.
d. Vertical clearance 120'.

TABLE II—GREAT LAKES NAVAL CONSTRUCTION FOR ARMY, NAVY AND AIR FORCE FROM 1951 TO 1956

	Type	No.	Tons
Builders with Vessels 100 Tons or Over			
American Ship (Lorain, Ohio)*	Navy LST's	2	8,300
Burger Boat (Manitowoc, Wis.)	Navy Minesweeps	7	4,100
Christy Corporation (Sturgeon Bay, Wis.)	Navy LST's	5	14,200
Defoe Shipbuilding (Bay City, Mich.)	Navy DE's	2	2,800
Grebe Shipyard (Chicago, Ill.)	Navy Minesweeps	3	1,000
Kewaunee Engineering (Kewaunee, Wis.)	Army LCT's	33	10,100
Marinette Marine (Marinette, Wis.)	Army Barges	10	2,500
Peterson Builders (Sturgeon Bay, Wis.)	Minesweeps	9	7,100
Totals		71	50,100†
Builders with Vessels Less than 100 Tons			
Beacon Boat (Holland, Mich.)	40' Utility Boats	26	200
Chris Craft (Algonac, Mich.)	52' Rescue Boats	2	40
Defoe Shipbuilding (Bay City, Mich.)	Plastic (MSB)	1	30
Detroit Basin (Detroit, Mich.)	Aircraft Rescue	15	500
Kargard Boat & Eng. (Marinette, Wis.)	Barges	115	7,500
Lock City Mach. & Mar. (Sault Ste. Marie, Mich.)	LCM's & Utility	104	2,130
Marinette Marine (Marinette, Wis.)	LCM's	151	3,900
Matthews Shipbuilding (Port Clinton, Ohio)	40' Utility Boats	47	400
Northeastern Boiler (Green Bay, Wis.)	Cargo Barges	15	975
Olson Shipyards (Chicago, Ill.)	LCM's	7	470
Peterson Builders (Kewaunee, Wis.)	LCU's	5	200
Roamer Boat (Holland, Mich.)	Steel Tugs	31	800
Rogers Boat Yard (Northport, Mich.)	35' MB's	3	30
Ray Greene (Toledo, Ohio)	Plastic Dinghys	106	21
Hacker Boat (Mt. Clemens, Mich.)	45' Picket Boats	9	153
Huron Charlevoix (Charlevoix, Mich.)	Rescue Boats	1	24
Totals		638	17,400†

* Note: In September, 1956, American Ship Building was awarded a contract to construct two DE's.
Note: In addition, two Great Rivers Builders, Kelly Ryan (Blair, Neb.) and Missouri Valley (Leavenworth, Kan.) constructed 48 small vessels totaling 5,600 tons.
† Nearest 100 Ton.



Courtesy St. Lawrence Seaway Development Corporation

DWIGHT D. EISENHOWER LOCK, ST. LAWRENCE SEAWAY

The completion of the St. Lawrence Seaway project will open new opportunities and offer new challenges to Great Lakes shipbuilders. The artist's conception of the Dwight D. Eisenhower Lock, shown above, illustrates the fact that the Seaway will permit Lakes-built vessels to compete in size with those built on our seacoasts. Construction of this lock is already underway.

One of the most important of these future projects is the deepening of the connecting channels between Lake Erie and Lake Huron and at the Straits of Mackinac to a depth of 27 feet. This work will cost about $100,000,000, but it will save an estimated $10,000,000 per year in transportation costs. Congressional authorization for this work has progressed far already. H. R. 2552 has been approved by the House, and the Wiley bill (S. 171) is receiving Senate consideration.

The second, and almost equally important project, is to build a twin set of locks for the five single locks in the Welland Canal. When that is done, all of the eight locks will have counterparts, and the canal's potential will be increased by an estimated 16,000,000 tons annually. Since the canal is located entirely in Canadian territory, this project depends on Canadian approval. In spite of the estimated $100,000,000 price tag for the job, most authorities feel that Canada will act affirmatively in time so that Welland will not be the bottleneck some shipping circles have predicted it will be in a decade or two.

How will we use the seaway that is now being built? An increasing number of small vessels, especially foreign ones, have been using the present outmoded seaway. Their number could increase to undreamed-of proportions and competitive power when the gates are opened two years hence. If automobiles can make the all-water trip from Chicago to Rotterdam at an estimated seventeen per cent saving in freight, and farm implements can realize a whopping 43 per cent saving, there is little doubt that the new seaway will be used. But, by whom? Who will build the vessels? Will the Great Lakes and Great Rivers shipbuilders raise the inland shipbuilding industry to the same commanding position that their associates in the area have done in other industries? Will the Great Lakes ship operators insist on increasingly efficient vessels so that they can set new cost records like the fifth of a cent per ton-mile for bulk cargos that has been equalled nowhere else in the world? Will our shipbuilders staff themselves adequately for the jet-propelled technological changes underway? Will they let "past practice"—that almighty law of shipbuilding—control, or will they use it meaningfully for greater achievements?

The challenge of the seaway is going to tax the resourcefulness of Great Lakes shipbuilders. They enter an era of broader and stiffer competition. Judging from past performance, however, we have good reason to believe that the success story of naval construction on the Great Lakes will be continued.

"THE WELDING JOURNAL"

HIGH-FREQUENCY CONTINUOUS SEAM WELDING OF FERROUS AND NONFERROUS TUBING

ACKNOWLEDGEMENT

The December 1956 edition of "The Welding Journal" published this article by H. B. Osborn, Jr., of The Ohio Crankshaft Company, Cleveland, Ohio. It was presented at the 1956 National Fall Meeting of The American Welding Society, held in Cleveland, Ohio.

INTRODUCTION

THE APPLICATION of high-frequency (well above 60 cycles) electrical energy to the continuous electrical seam welding of tubing has introduced into this field many new advantages. These include:

1. Increase of several hundred percent in welding speed.
2. Use of hot-rolled material.
3. Accurate control of upset.
4. Welding of materials other than steel.
5. Welding of extremely-thin-wall stock.
6. Greater flexibility and less maintenance.

The high-frequency energy may be applied to the material to be heated for welding by either subjecting the strip or tube to magnetic flux (*induction heating*) which will cause current to flow in the desired areas; or by making direct electrical contact (*resistance heating*) which will also cause current to flow. In either case the resultant I^2R losses develop the heat necessary for welding.

DISCUSSION OF ADVANTAGES

Increased Weld Speed

When a frequency of 60 cycles, or even 180 cycles for that matter, is used with the conventional low-frequency resistance method, the speed of welding is limited because of the well-known "stitching" effect which appears and which is determined by the frequency.

With high-frequency welding this is eliminated and tube mills are in production processing tubing at the rate of 300 fpm—by the induction method, using 10,000-cycle equipment. Before this was an accomplished fact, a considerable amount of redesign of the mill was necessary for operation at these higher speeds and the present speed is limited only because of the mill. If a mill can be produced which will satisfactorily handle strip (cold) and convert it to tubing, maintaining the close tolerance necessary —even at speeds of 1000 fpm—induction heating can be used for welding.

Surface Condition

The low-frequency contact-resistance method requires a clean surface. Thus it is necessary to use strip which fulfills this specification; that is, a hot-rolled strip which has been pickled or one that has been cold rolled. At higher frequencies, however, this is not a factor and no surface preparation is required. With the induction method where there is no contact made by the "inductor" with the material, it is practical to weld regardless of surface condition, e.g., even hot-rolled skelp. Edge preparation from a slitting operation is recommended in all cases so that the abutting surfaces are clean.

The cost savings to be gained because of the advantage are not applicable if the tubing produced must eventually be cleaned before subsequent use; that is, if plating or other operations follow.

Upset

Characteristic of high-frequency heating is the

flow of energy on the surface. Thus, when the heating is confined to the edges of the strip to be welded, proper adjustment of roll pressure and heat pattern makes it possible to control the amount of upset, particularly on the inside where it will be nothing more than a slight bump as contrasted to the rough flash characteristic of conventional resistance-welded tubing. This has been very advantageous in the instance of electrical conduit where a rough flash cannot be tolerated.

Material

Low-frequency resistance mills have been in successful operation for years on ferrous materials, generally low- and medium-carbon steels. Certain other materials such as alloy steel, stainless steel, aluminum, bronze and brass had never been satisfactorily processed. High-frequency induction and resistance mills are now a reality on all these materials.

Thin-Walled Tubing

With rotary electrodes, the heat is necessarily not confined to the very edge of the strip. Thus it had been practically impossible to weld very-thin-walled (less than approx. 0.030 in.) tubing since it cannot withstand the extreme pressures applied. This is particularly true with those having a narrow plastic range such as aluminum.

The high-frequency technique has made it possible to weld tubing but 0.010 in. thick.

Flexibility and Maintenance

Conventional rotary electrodes have to be changed for but slightly different tube sizes. Further, these must be refinished or replaced as they become worn.

Neither situation prevails with high-frequency induction welding, thus providing greater flexibility and less maintenance. The contact shoes used for high-frequency resistance welding, because of their size and the handling of less current, enjoy these same advantages.

FORGED WELDS

High-frequency welding can produce a forged weld as contrasted to a cast weld. By "forged" it is meant that the edges of the seam have been heated to a high enough temperature in the plastic range of the material to be forged together under pressure and at no time has the metal become liquid. The well-known electric resistance weld tube mills employing rotary electrodes cause current to flow by making contact on either side of the seam. The electrical resistance of the seam to the flow of this current melts the abutting edges following which the squeeze rolls press such edges together into a homogeneous structure. This same phenomenon occurs with high-frequency induction welding with certain types of inductors and with high-frequency resistance welding. However, with the properly designed inductors and correct welding procedure, high-frequency forged welded tubing is being produced. As will be recognized, this is highly desirable from a strength standpoint. Pipe so produced has been approved by the American Petroleum Institute (API) and many miles are already in use.

HIGH-FREQUENCY RESISTANCE WELDING

Conventional roller-electrode resistance welders operate generally at 60 or 180 cycles. Higher frequencies permit faster welding speeds as pointed out in a previous part of this paper. There is another advantage though; namely, that, as the frequency is increased the current for equivalent power is reduced due to higher voltages. At 500 kc the advantage may be as much as 100:1. Also, the higher the frequency the more readily can the heat be confined to a shallow depth from the seam edge. However, suitable electrodes must be designed to introduce as much of the current as possible into the seam edges and thus decrease the amount of power needed for a given wall thickness. A further advantage to the lesser amount of metal heated is that smaller diameters and thinner walls can thus be processed. This latter point will be discussed in more detail under "High-Frequency Induction Welding" since the same reasoning follows regardless of how the high-frequency current is applied.

The fullest advantage is gained when the contact is made only against the seam edges and not by means of flanged roller electrodes which also make contact with the surface of the tube adjacent to the seam edges. That portion of such electrodes which contacts this surface rolls on it, making point to point connection. That portion which contacts the seam edge will slide against it. This, therefore, suggests the use of shoes introduced into the seam providing all current flow through slide contact against the seam edges. On small diameters, due to space limitations these shoes are generally applied to the outer surfaces of the tubes adjacent to the seams.

This type of sliding-contact high-frequency resistance welding is being used on a variety of tubing (Fig. 1). Some maintenance problems have been encountered. The edges of the seam as they approach the seam joint present a path for the high-frequency current of relatively low impedance compared to

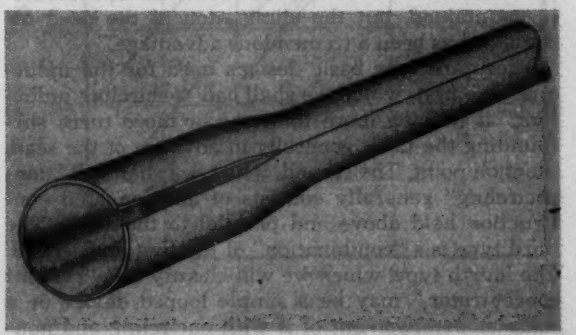


Figure 1. High-frequency resistance welding with contact shoes. Metallic contacts held against seam edges are connected to high frequency power, and are separated by an insulating member. On small diameters, shoes are against outer surfaces adjacent to seam.

other parallel paths circumferentially around the tube. The current flows to and across the seam joint where heating is of sufficient magnitude to permit welding.

In Table I are data on production mills, indicating the present scope of this technique. High frequency used was 50 kw at 450,000 cycles.

TABLE I

Material	Wall, in.	Speed,* fpm	Material	Wall, in.	Speed,* fpm
Al	0.025	200	Brass	0.025	112
Al	0.035	200	Brass	0.050	80
Al	0.045	175	Brass	0.080	60
Al	0.051	150	Stainless Steel	0.031	137
Al	0.062	130	Stainless Steel	0.050	110
Al	0.081	110	Stainless Steel	0.109	72

* Speed independent of diameter above ⅜ in. OD and varies considerably with application, e.g., ⅜ × 0.035-in. steel has been welded at 400 fpm.

HIGH-FREQUENCY INDUCTION WELDING

The art of high-frequency induction welding of tubing would appear to be quite old. A patent filed in 1928, and subsequently issued, carries claims which read in part, "The method of continuously welding open-seam metal tubes by induction . . . progressively advancing an open-seam metal tube, bringing the seam edges together into closer and closer proximity during the longitudinal movement thereof until said edges are sufficiently close . . . inducing in the metal a current flow for heating the seam . . . bringing the edges completely together to cause concentration of flow of induced current and impressing the edges together to weld the pipe . . ."

It sounds very simple, but it has taken many years of research and development and refinement of technique to put the process on a production basis. The refinements have concerned themselves primarily with the design of the inductors used and a thorough understanding and control of the flow of current. These have been sufficiently important to allow the issuance of dozens of additional patents. Thirteen, for example, have been granted to the author's company during the last five years alone. The relative position of the inductor to the tube must be accurately maintained, but the elimination of the need for contacts has been a tremendous advantage.

There are four basic designs used for the inductors. The first, which we shall call "encircling inductors," is nothing more than one or more turns surrounding the tube, generally in advance of the seam junction point. The second, which we shall call "non-encircling" generally consists of an elongated construction held above and parallel to the seam. The third type is a "combination" of the first and second. The fourth type, which we will classify as a "current concentrator," may be a simple looped device or a complex arrangement of it with encircling and non-encircling means. We are, however, quite aware that the expression "current concentrator" could be applied to *any* inductor used.

1. *Encircling Inductor.* The open-seamed tube is

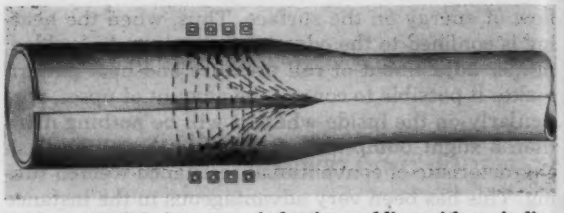


Figure 2. High-frequency induction welding with encircling type of inductor. Shows 4-turn, water-cooled inductor and current flow induced in tubing.

fed progressively through the inductor and is gradually closed to produce a weld from the heat which has developed along the edge of the seams and has concentrated at the seam junction point. There has been considerable controversy in the patent literature concerning the location of this point: that is, whether it is within or without the physical confines of the inductor or within or outside the magnetic field created by the inductor. It is necessary to maintain the seam open as it goes into the coil, and a non-conductive guide is generally used. This also serves the additional purpose of maintaining the position of the seam through the pressure rolls—a very essential control.

The encircling inductor induces, by the usual process of electromagnetic induction, a circumferential flow of current. This current, however, cannot flow across the open seam and, therefore, flows down the tube to the seam junction point. There is an increasing concentration of current density as we approach an intense concentration and arcing at this point which produces sufficient heat to melt the metal which is instantly pressed together and welded (Fig. 2).

While the current flow is concentrated essentially in the seam edges, this design produces some flow of current in all portions of the tube at some sacrifice in efficiency.

Inductors of this type have been used at various frequencies and on both ferrous and nonferrous materials. However, they have been most successful in the welding of thin-walled nonferrous tubing, generally aluminum, and operating from a vacuum-tube oscillator at approximately 450,000 cycles.

In Table II are data on production mills, indicating the present scope of this technique.

TABLE II

Material	Tube size		Power, kw	Welding speed, fpm
Wrought iron	1 in. diam	× 0.012 in.	35	75
Aluminum*	1 in. diam	× 0.050 in.	50	100
Aluminum	4 in. diam	× 0.049 in.	19	160
Aluminum	1 in. diam	× 0.049 in.	17	200
302 Stainless steel	1 in. diam	× 0.064 in.	25	68
304 Stainless steel	⅝ in. diam	× 0.020 in.	18	100
70/30 Brass	1½ in. diam	× 0.035 in.	16	150

* Data for 1-in. aluminum tubing shows wide discrepancy (6:1) due to quality requirements.

2. *Nonencircling Inductor.* The open-seamed tube is fed progressively under the inductor and is gradually closed to produce a weld from the heat which has been developed along the seam edges. The point at which the seam is closed may be under the inductor or after the tube has left the inductor, just so long as the temperature is high enough when the pressure rolls "forge" the edges together.

With this design, a seam guide is advantageous to provide an open seam as the strip goes under the inductor and to control the position of the seam in the pressure rolls. However, it is absolutely necessary to have this guide to accurately position the seam with respect to the inductor so that the edges to be heated are kept beneath the center leg of the inductor which carries a flux concentrating device. This heats a minimum depth of metal back from the seam edge which results in the small amount of upset.

This type inductor usually consists of three parallel conductors with the center conductor opposite the edges of the seam to be heated and provided with magnetically permeable material so as to induce high-frequency current in the edges of maximum concentration or density. The other two conductors are spaced away from the edges but more or less adjacent to the surface of the tube so as to create electrical coupling and induce current in that area, but at low density (Fig. 3). (In some installations these side arms are remote to the tube surface, even above the level of the central conductor, in order to provide easier clearance for the pressure rolls.) An air gap of approximately 0.080/0.100 in. is maintained between the tube and the center leg.

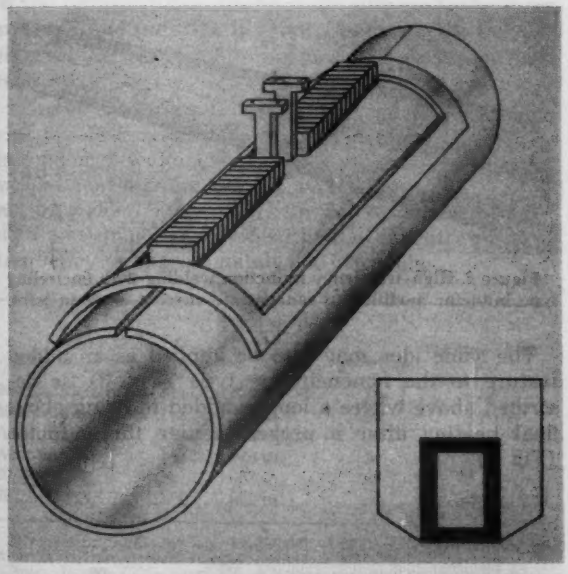


Figure 3. High-frequency induction welding with nonencircling laminated inductor. Inset shows how U-shaped laminations (0.007 in. thick for 10 kc) are stacked on center leg.

Table III shows representative data on production mills indicating the present scope of this technique for low- and medium-carbon steel.

TABLE III

Frequency	Tube size		Power, kw	Welding speed, fpm
4,000 cycles	2 in. diam	× 0.020 in.	200	200
8,300 cycles	1½ in. diam	× 0.150 in.	600	200
10,000 cycles	½ in. diam	× 0.049 in.	250	200
10,000 cycles	2 in. diam	× 0.065 in.	250	150
10,000 cycles	8⅝ in. diam	× 0.141 in.	130	25

A similar set of data for E.M.T. conduit welded at 10,000 cycles using 270 kw is shown in Table IV.

TABLE IV

Tube size, in.	OD, in.	Wall, in.	Welding speed, fpm
½	0.706	0.042	210
¾	0.922	0.049	200
1	1.165	0.058	180
1¼	1.510	0.065	150
1½	1.740	0.065	150
2	2.197	0.065	150

The mill processing conduit per the above data has been in operation since 1950 and averages approximately 50,000,000 ft. per yr. The strip-to-conduit yield is 96%. This figure includes trimming losses for the wide coils, material consumed for test set up on size changes and end weld losses.

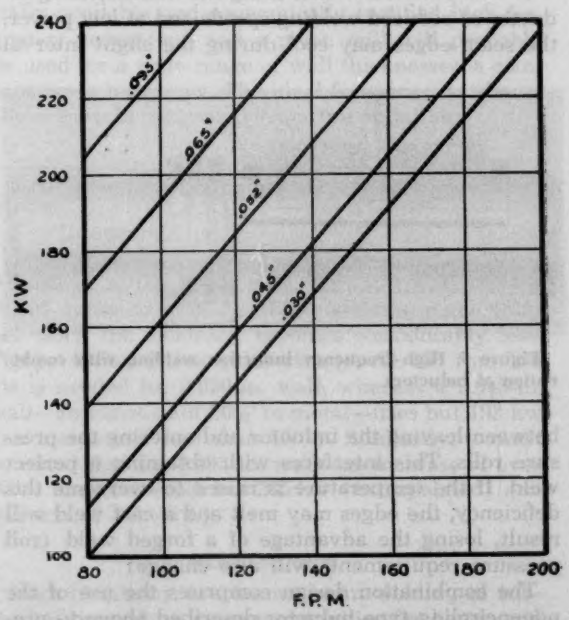


Figure 4. High-frequency induction welding low-carbon steel tubing at 10,000 cycles. Power vs. speed for various wall thicknesses and ¼ in. OD or larger. Lines are averages of a scatter of a large number of production runs. (0.080 in./0.100 in. in air gap.)

The chart identified as Fig. 4 shows the power requirements at 10,000 cycles for welding various sizes of tubing at relatively high speeds. At lower speeds, heat loss by conduction circumferentially reduces efficiency considerably.

The air gap between the inductor and the seam affects the efficiency of welding. Pipe has been run at 10,000 cycles with an air gap considerably less than that applicable to the above data (Table V).

TABLE V

Diam., in.	Wall, in.	Power, kw	Speed, fpm	Air gap, in.
4	0.187	100	30	0.040/0.050
8⅝	0.141	130	25	0.080/0.100

With the smaller gap, more metal has been welded with less power and at greater speed. The improvement has been about 100%.

Unfortunately, it has been found impractical to maintain, on a continuous production basis, the small air gap indicated above. Further, under such conditions momentary changes in gap corresponding to deviations of the seam from parallelism with the inductor result in undesirable temperature variations. Additionally, scale from hot-rolled strip will introduce serious problems by often filling up the gap despite wiping and blowing devices. Although at considerable loss in efficiency, these difficulties are not encountered at the 0.080/0.100-in. air gap which is recommended for production.

3. *Combination.* When using the nonencircling inductor at reduced welding speeds and at low power, the seam edges may cool during the slight interval

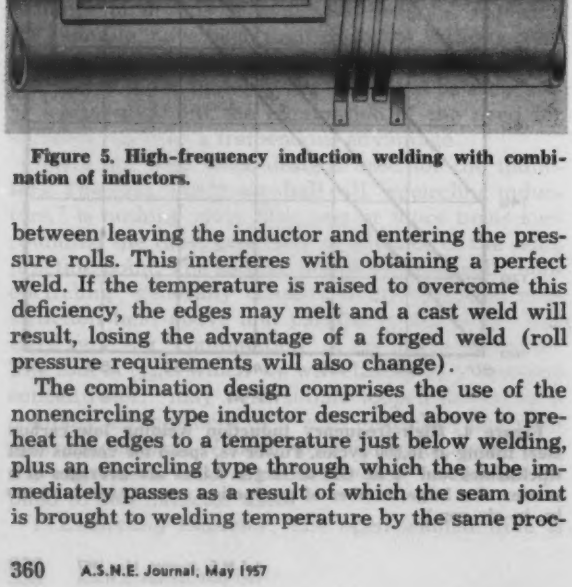


Figure 5. High-frequency induction welding with combination of inductors.

between leaving the inductor and entering the pressure rolls. This interferes with obtaining a perfect weld. If the temperature is raised to overcome this deficiency, the edges may melt and a cast weld will result, losing the advantage of a forged weld (roll pressure requirements will also change).

The combination design comprises the use of the nonencircling type inductor described above to preheat the edges to a temperature just below welding, plus an encircling type through which the tube immediately passes as a result of which the seam joint is brought to welding temperature by the same process as shown in Fig. 2. However, in this instance there need be no melting take place, as when using the encircling type alone, since the edges, being already at a high temperature, have a high resistivity; thus, with less current flowing, there is no tendency to melt at the junction point (Fig. 5).

4. *Current Concentrator.* Admittedly, all inductors used in the induction heating field are basically current concentrators—as are certain parts of specially designed inductors. However, the connotation here is meant to apply to devices intended, by special techniques, to concentrate the current in the area of the seam joint much the same as accomplished by the "encircling" type described above but more efficiently.

The simplest approach to this is to change the shape of an encircling type of inductor so that it conforms to the shape of the seam joint region. This corresponds to introducing a loop or hairpin parallel to the seam which will cause an increase in the current flow by the closer proximity of the inductor legs or loop to the edges to be heated (Fig. 6).

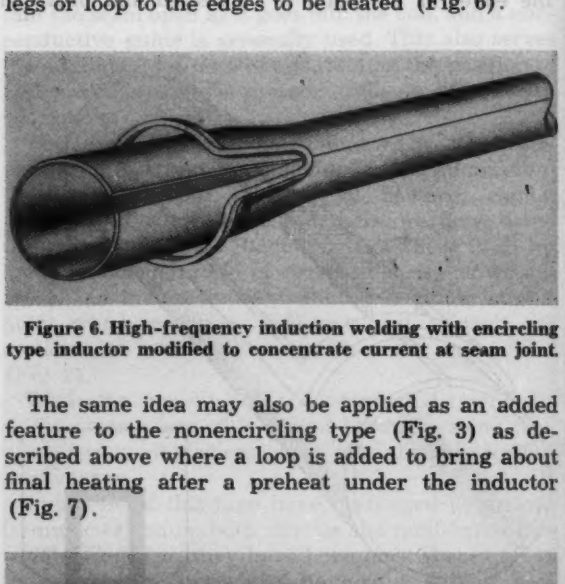


Figure 6. High-frequency induction welding with encircling type inductor modified to concentrate current at seam joint.

The same idea may also be applied as an added feature to the nonencircling type (Fig. 3) as described above where a loop is added to bring about final heating after a preheat under the inductor (Fig. 7).

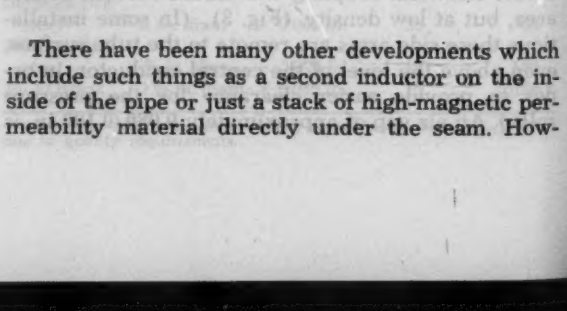


Figure 7. High-frequency induction welding with nonencircling inductor to which current concentrator has been added.

There have been many other developments which include such things as a second inductor on the inside of the pipe or just a stack of high-magnetic permeability material directly under the seam. How-

ever, a thorough study of all these factors and the several inductors described so far, along with modifications thereof, has resulted in the adoption of a slightly modified concentrator which had been used successfully for many years for induction-heating requirements such as surface hardening and brazing. For the purpose of this paper, we shall call it the "current concentrator."

Basically, it consists of a "primary," multiturn coil accurately matched to the output of the high-frequency generator; a "secondary" device efficiently coupled to this primary and connected to a loop positioned over and in advance of the seam joint. The multiturn coil (primary) may, for convenience, encircle the tube or, if preferred, be adjacent to it. The "secondary" partially encircles the tube in advance of the seam joint, but it is within the "primary." The loop is in series with the "secondary" and carries a high current flow. Its shape and position over the seam and joint and close proximity thereto results in a corresponding current flow in the seam edges and across the joint which is readily controlled to produce the correct "forged" welding temperature. While temperatures can be made sufficiently high to produce melting, this is intentionally avoided so as to preclude the formation of undesirable cast structure.

The concentrator is suitable for various frequencies but is currently being used primarily at radio frequencies, welding small and medium-sized thin-walled non-ferrous tubing which heretofore could not be welded successfully. In Table VI are welding data on tubing processed with the concentrator at a frequency of approximately 450,000 cycles.

TABLE VI

Material	Tube size	Power, kw	Welding speed, fpm
304 Stainless steel	1¼ × 0.050 in.	18	60
304 Stainless steel	1¼ × 0.046 in.	20	80
Aluminum	1¼ × 0.049 in.	10	80
Aluminum	1¼ × 0.046 in.	20	77
70/30 Brass	1¼ × 0.062 in.	20	27
70/30 Brass	1¼ × 0.062 in.	50	150

Note: Aluminum—10 kw produced weld for structural tubing whereas 20 kw needed for high-pressure pipe.
Note: Brass—150% increase in power resulted in 450% greater welding speed due to less heat flow by conduction from edges to body of tube.

FREQUENCY

So far in this presentation little has been said of the effect of frequency. This factor is of the utmost importance and must be taken into account in connection with the wall thickness of the material.

The higher the frequency, the shallower will be the depth of penetration of current and resultant heat. When considering this "depth" as being from the edge of the seam inward circumferentially, it would appear that it would be desirable to use as high a frequency as possible; certainly, at least approximately 450,000 cycles as available from standard commercially produced oscillators. The limiting of the amount of metal heated makes for better upset control and lower power. When welding thick-walled tubing, the "depth" from the standpoint of measurement from the surface inward radially, must also be taken into account. One might thus conclude that, in such cases, a low-frequency of say 1000 cycles should be used. However, if the frequency selected has a depth factor many times greater than the wall thickness, inefficiency will result because there is not enough metal present upon which the magnetic flux can react and through which the induced current can flow. With depth factors much less than the wall thickness, heat flow by conduction must be relied upon. Since this is slow, the frequency cannot be too high. Thus we must consider the relationship between wall thickness and frequency. For reference purposes Table VII shows the approximate depth of penetration in steel heated to welding temperatures for several frequencies.

TABLE VII

Frequency, cps	Depth, in.
1,000	0.728
3,000	0.420
10,000	0.230
20,000	0.163
450,000	0.034

For the most efficient heating, the frequency selected should have a corresponding depth factor which is approximately the same as the wall thickness. But since it is only practical to use commercially available and economically justified high-frequency generators, and a given mill will probably be used for a wide range of wall thicknesses, a compromise is necessary. The ideal frequency as shown above may be estimated from the equation:

$$F = \frac{530}{D^2}$$

where

F = frequency,
D = depth, in.

According to the above data, the ideal wall size for 10,000 cycles is 0.230 in. When welding much thinner stock the efficiency becomes considerably less. Figure 4 shows this quite clearly. At 150 fpm 180 kw is needed for 0.030-in. wall, whereas a 0.045-in. wall—an increase of 50% in metal—uses but 193 kw (an increase of less than 10%). Similarily, it must be noted that the 0.095-in. wall—an increase of over 200% in metal—uses but 285 kw (extrapolated) (an increase of but 48%).

CONCLUSIONS

High-frequency continuous seam welding of tubing has opened up new opportunities for better and cheaper production of tubular stock. New materials, faster welding speeds, higher quality of weld, and particularly being able to weld thinner-walled stock, have justified the installation of many new tube mills

during the past few years, simply because of the application of high frequency.

This paper has dealt almost exclusively with the several technical aspects of the welding action which takes place in a space of but a few inches on an installation occupying many feet. While some rather casual reference has been made to air gap, to the alignment of seam and pressure rolls, it must be pointed out that the success of high-frequency welding can only be achieved with proper adjustment and control of all the factors governing the forming of the tubing, matching of the abutting edges of the seam, and control of the position of the inductor. At high operating speeds, the fullest advantage can be taken of high-frequency welding, but the average tube mill does not generally operate this fast; if it is just speeded up, it will not hold the close tolerances required. Taking a conventional mill, replacing the welding heads with high-frequency induction equipment as described in this paper, and then increasing the speed does not make a high-frequency mill. Conversions, if contemplated, should only be undertaken by the mill manufacturer or by a user with the full knowledge of the necessary requirements and the technical help to accomplish them. Also, one should be aware that the design features of the inductors and processes described in this paper and many modifications thereof are covered by patents.

This technique for welding of tubing has been a real challenge to the tube mill manufacturers who have been able to produce the equipment necessary to meet the speed and control specifications of the high-frequency method. The relatively large number of mills in operation or on order today attest to the fact. However, there is still the challenge of higher speeds—certainly, taking a strip and converting it into a tube and then getting rid of it in accurately cut lengths at 300 fpm is quite a task. But as has been stated we are ready to weld at 1000 fpm if and when somebody figures out the "minor" problems connected with a tube mill operating at that speed.

ADDENDUM—HIGH FREQUENCY ANNEALING OF SEAM-WELDED PIPE

Although the contents of this paper probably should be limited to "welding" (because of the title), it was thought appropriate to add a brief note about the use of high frequency for annealing after welding.

In order to satisfy the physical requirements of certain classes of large diameter (4–26 in.) heavy-walled resistance-welded pipe, the "brittle" cast weld must be annealed. Several old mills have been so equipped with high-frequency units for heating only the weld. Others have resorted to the rather inefficient method of treatment whereby the entire pipe is heated. However, the mills most recently installed or about to be, will, in all probability, use high-frequency seam-weld annealing units. The same type of inductor as described in Fig. 3 is used with the side arms positioned above the center leg and the same inductor serves for all diameters.

In the fabrication of zirconium, processes like welding, casting, melting, alloying, in which the metal becomes molten, must be handled with special techniques because of zirconium's extraordinary affinity for gases in the melting temperature range. Melting must be done in a vacuum or inert gas atmosphere. Consumable electrodes are used in the melting furnaces which are of the same composition as the desired melt. Welding is often performed inside a vessel filled with argon, although argon-shielded electrodes may be used in many cases without special enclosure. Flash butt welds are made in an argon atmosphere.

"MECHANICAL ENGINEERING"

THE LIQUID-METAL-FUEL REACTOR CLOSED-CYCLE GAS-TURBINE POWER PLANT

ACKNOWLEDGEMENT

The August 1596 edition of "Mechanical Engineering" published this article. It was written by L. D. Stoughton and T. V. Sheehan, both of the Mechanical Engineering Division of Brookhaven National Laboratory.

THE CONCEPT of the gas-cooled reactor has been familiar to the nuclear-energy field since the first reactors were constructed. However, these early reactors were primarily for research purposes or production of fissionable materials and not intended for the production of power. Atmospheric air or other low-pressure gases were often used or proposed as reactor coolants. The resultant high pumping power, low heat-transfer rates, and temperature limitations resulting from corrosion by atmospheric air left something to be desired from the standpoint of the power industry.

As a result of advances in the art of fabrication techniques for reactor-fuel elements, there now exist some promising types of high-temperature solid-fuel elements. When these elements are used to heat an inert gas, corrosion problems are greatly reduced if not eliminated entirely. The thermodynamic performance of the reactor core can be enhanced by using heat-transfer passages of small hydraulic radius and by raising the gas pressure. This will give higher heat-transfer rates at a lower pumping power. Furthermore, if a satisfactory barrier can be maintained between the reactor fuel and the reactor coolant, then this heated gas can be used directly in a gas-turbine cycle.

NUCLEAR-POWER-PLANT PROPOSALS

Current interest in the nuclear gas-turbine power plant is shown by a number of recent proposals. The Gas and Electric Department of the City of Holyoke, Mass., has proposed the construction of a 15,000-kw closed-cycle gas-turbine power plant with a solid-fuel-element nuclear reactor as the heat source (1). This proposal is part of the Atomic Energy Commission's Power Reactor Demonstration Program. Nine concerns, including the American Turbine Corporation, AMF Atomics, Atomics International, Ford Instrument Company, General Atomics, General Electric, Cleveland Diesel Engine Division of General Motors, Nuclear Development Corporation of America, and the Pacific Coast Nuclear Power Group have recently submitted proposals to the Maritime Commission for the development of a nuclear gas-turbine power plant for merchant vessels (2).

The purpose of this paper is to present the concept of a nuclear power plant which combines the advantages of a liquid-metal-fueled reactor with those inherent in a closed-cycle gas turbine. Extensive development work on the closed-cycle gas turbine has been carried on by the Escher Wyss Engineering Works of Zurich, Switzerland. Progress in this work has been periodically reported to the ASME by Dr. Curt Keller of Escher Wyss (3, 4, 5).

The major advantages of the closed-cycle system result from its ability to use a clean, inert, high-pressure gas as the working fluid. Turbomachinery sizes for units up to 200,000 kw net output remain within practical limits because turbine exhaust is at a relatively high pressure. Fluid passageways of small hydraulic diameter can be realized through the use of the clean, dry, and inert working fluid, resulting in compact arrangements for the recuperator, precooler, and intercooler. Output can be varied by changing pressure level which results in good part-load efficiency. Gas is added or removed from the system through apparatus located in the low-temperature portion of the cycle. Cooling-water requirements are reduced because of sensible-heat

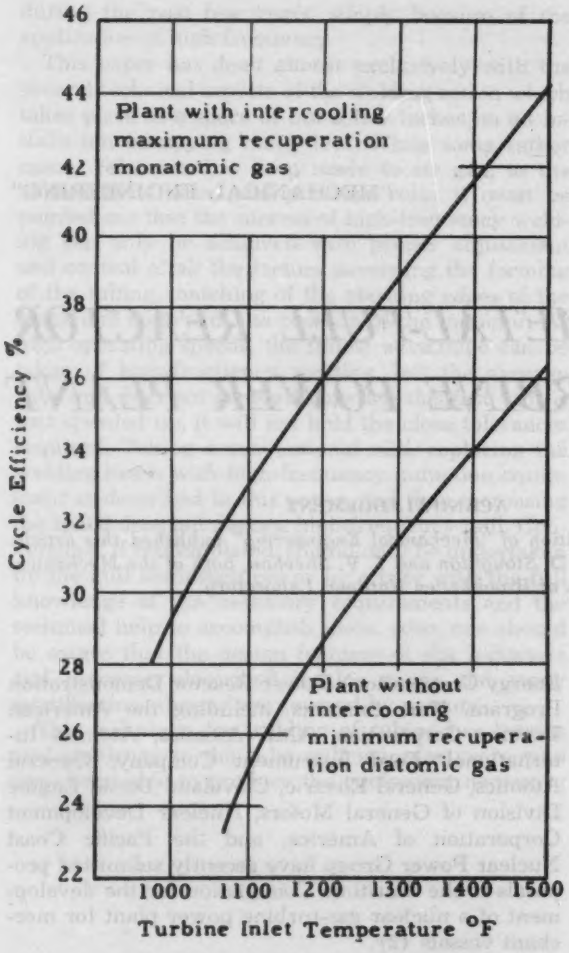


Figure 1. Range of closed-cycle gas-turbine efficiencies.

rejection from the system instead of latent-heat rejection.

The closed-cycle turbine can utilize higher-temperature materials efficiently as they become available because of the absence of corrosion and deposition problems. Fig. 1 (6) shows the thermal efficiencies that can be obtained with turbine-inlet temperatures in the range of 1100° to 1500° F. The liquid-metal fuel which is under study at the Brookhaven National Laboratory (BNL) is a potential high-temperature heat source for this closed-cycle gas-turbine system.

LIQUID-METAL FUEL

This reactor fuel is being developed by the Nuclear Engineering Department at BNL for use in the liquid-metal-fuel reactor (LMFR). The LMFR is currently designed to produce 900° to 975° F steam for a central-station power plant with a rating of 200,000 kw and it will be capable of breeding as much fissionable material as it consumes (7).

The reactor fuel is a solution of uranium dissolved in molten bismuth. Bismuth is one of the heavy metals, melting at 520° F and having a density of 600 pcf at 1200° F. It has a boiling point at atmospheric pressure of 2691° F which makes it suitable for high-temperature applications without necessarily requiring high pressure. Its low absorption cross section for thermal neutrons (0.032 barns) results in good neutron economy for the reactor core. Fig. 2 shows the solubility of uranium in bismuth as a function of temperature, and includes the effect of magnesium and zirconium which are added to inhibit corrosion. Most of the reactor cores considered at BNL have critical uranium concentrations which are well within the solubility limits.

There are certain outstanding features of uranium bismuth when it is used as a liquid reactor fuel:

1. It can be circulated through the core at a sufficient rate to carry the heat generated in the reactor core to an external heat exchanger. This means that core-design parameters need not include heat-transfer surface.

2. It is not subject to radiation damage, which is a factor that seriously influences the usable life of a solid-fuel element. However, bismuth will absorb some neutrons and form the dangerous element polonium, but this hazard is considered not greater than that caused by the presence of fission products.

3. It can be handled by pumping and does not require the handling mechanisms and removable closures used with solid-fuel-element systems.

4. It can be processed continually; that is, fission products can be continuously removed from the system and fresh fuel added at a rate to compensate for the fuel consumed in the core.

5. There is no limit on fuel burnup which means that large quantities of unspent fuel are not required to be reprocessed.

6. Control mechanisms are not required because of the large negative temperature coefficient of reactivity which enables the reactor core to be self-compensating for load changes and because the

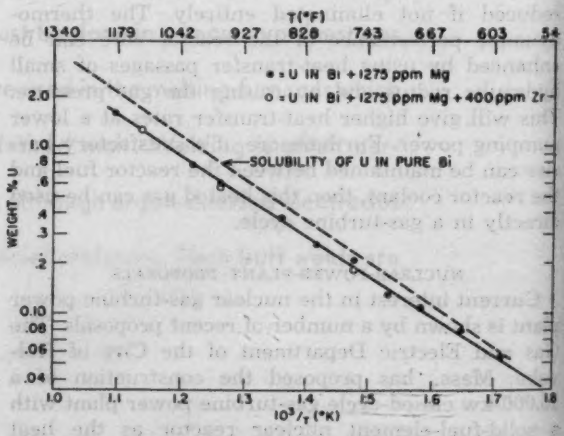


Figure 2. Solubility of uranium in bismuth versus temperature.

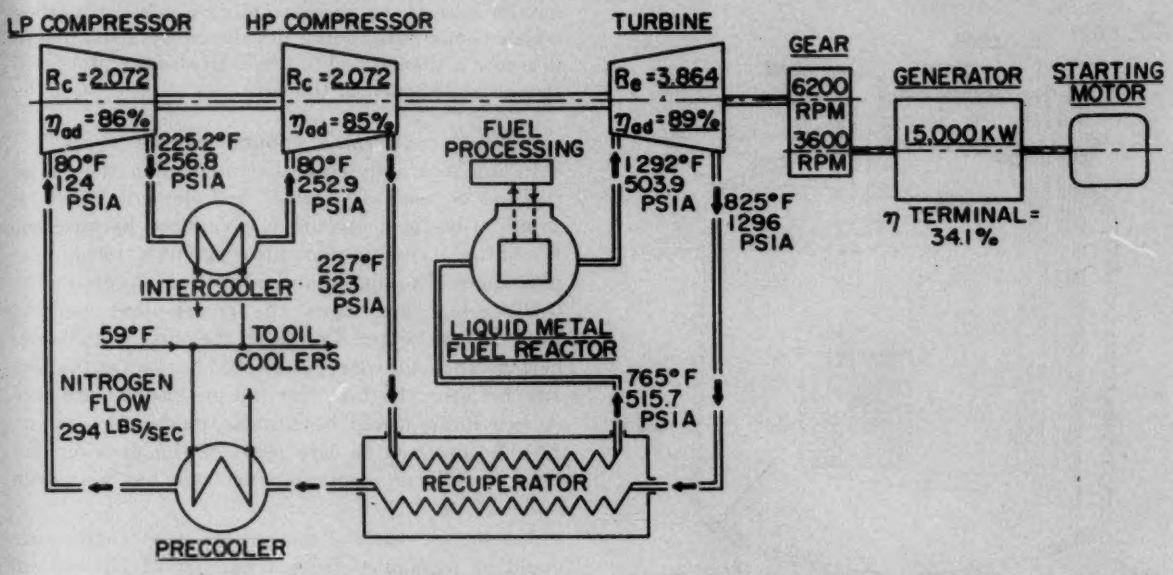


Figure 3. 15,000-kw liquid-metal-fuel-reactor closed-cycle gas-turbine power plant.

continuous addition of new fuel requires no excess inventory of uranium to be held in the core.

When a liquid-metal-fuel reactor is used as a heat source for a closed-cycle gas-turbine power plant, there are two fundamental arrangements which may be employed:

Externally Cooled. The cycle working fluid is heated in an exchanger, located outside the reactor core, through which the fuel is circulated.

Internally Cooled. The cycle working fluid is heated directly in the reactor core, with the fuel remaining essentially stagnant.

To illustrate the application of the externally cooled and internally cooled arrangements, we have selected as a power plant a closed-cycle gas turbine which is being designed for production by Escher Wyss and is available through that concern or its licensees. This unit has a rated output of 15,000 kw. It is designed to operate with nitrogen as the cycle working fluid in order to take advantage of the extensive air-turbomachinery experience. However, nitrogen will absorb a few of the thermal neutrons in a reactor core. The effect of pressure changes on reactivity and the presence of small amounts of radiocarbon (resulting from the capture of a neutron by a nitrogen atom) in the cycle working fluid remain to be assessed. Helium presents a more desirable choice because of its negligible thermal-neutron-absorption cross section and its excellent heat-transfer characteristics. Design of helium turbomachinery is currently being given serious consideration by Escher Wyss (5).

The cycle diagram is shown in Fig. 3. The gas is compressed from 124 psia to 256.8 psia in the first compressor, intercooled, and further compressed to 523 psia in the second compressor. After being heated to 765° F in the recuperator, the gas is further heated to 1292° F by the liquid-metal-fueled reactor. The gas then expands through a turbine which is mechanically coupled to the compressors and also drives the generator through a speed-reduction gear. The expanded gas gives up heat in the recuperator to the precompressed working fluid and returns through a precooler to the compressor inlet. The 15,000 kw is produced by a gas flow rate of 294 lb/sec at the pressure levels indicated in the foregoing. This cycle converts the nuclear energy into electrical energy at the generator terminals with an efficiency of 34.1 per cent.

EXTERNALLY COOLED REACTOR

The basic elements of an externally-cooled system include the reactor core where heat is generated in the uranium bismuth, a heat exchanger for transferring this heat to the cycle working fluid, and a pump for circulating the uranium-bismuth stream. As shown in Fig. 4, these elements can be contained in a single vessel which minimizes the uranium-bismuth inventory and somewhat simplifies the containment problem. Since the primary heat-transfer surface is not in the reactor core, the core design is relatively simple. A wide range of core sizes and compositions have been explored at BNL (8). This study included the three fissionable materials (U-233, U-235, and Pu-239), two moderators (graphite and beryllium), and a number of moderator-to-fuel ratios which included an externally moderated case (i.e., no moderator in the core, neutrons causing fission having been moderated in the reflector before returning to the core). The resulting core sizes ranged down to nearly 1 ft diam but for these

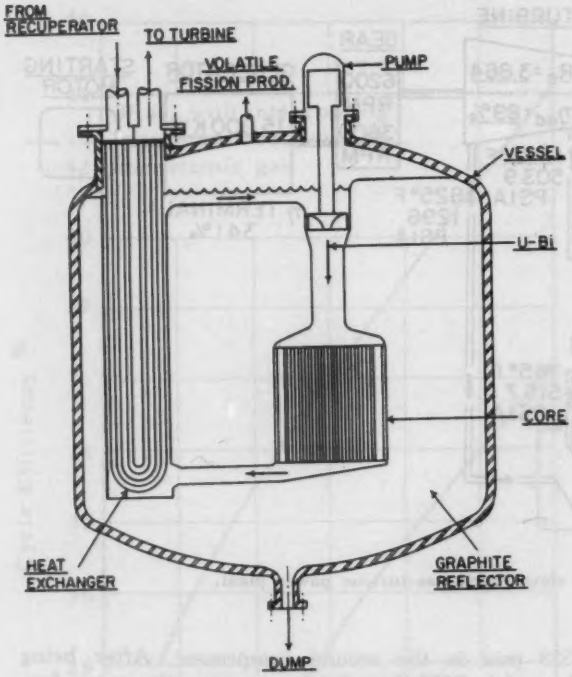


Figure 4. An externally cooled liquid-metal-fuel reactor.

very small cores, the fuel concentrations exceed the solubility limits and would require the use of slurry fuels which are also under development at BNL (9).

The 15,000-kw gas-turbine system will require a heat-generation rate of 150,000,000 Btu/hr. A total of 2500 gpm of bismuth containing 1500 ppm of uranium in solution enters the reactor core at 1200° F and is heated to 1500° F. The core is a 3½-ft. right cylinder of graphite with holes for the uranium-bismuth solution amounting to 50 per cent of the core volume. About 250 gpm of the fuel solution would by-pass the core and remove the heat generated in the 3-ft reflector. The 1500° F U-Bi then passes through the shell side of a tube-and-shell heat exchanger. The power-plant working fluid is heated to 1292° F as it passes through the tube side. The U-Bi is circulated back through the core by an axial-flow pump. This equipment is arranged in a single pressure vessel which is filled with graphite. The heat exchangers and pump are located in wells and can be removed by disconnecting flanges on the top head of the vessel. The pump can be driven by an electric motor or a turbine using the power-plant working fluid. U-Bi flows through passageways in the graphite. Volatile fission products can be removed from the free bismuth surface between the exchangers and the pump. About ½ gpm of U-Bi is continuously circulated through a processing plant which is located outside the vessel. Fission products are removed by contacting this U-Bi stream with a molten eutectic of certain chloride salts, a method which is currently being developed by BNL. Fresh uranium is then added to the U-Bi and the processed stream is returned to the core.

INTERNALLY COOLED REACTOR

In the internally-cooled arrangement, the liquid fuel can be used as a "fixed" fuel element. The total uranium-bismuth inventory is reduced because the liquid fuel is not circulated through an external heat exchanger. The high-temperature fuel is confined to the reactor core. Since the power-plant working fluid may be heated directly in the core for optimum performance, the moderator could best act as the barrier between the fuel and the gas. Either graphite or beryllium would be suitable moderators for an LMFR core but to date most of the development work at BNL on moderator materials has been done on graphite.

For the gas-turbine application, the reactor core could be assembled from a number of 1-ft cubical graphite blocks, each drilled with a set of vertical holes and a set of horizontal holes. A segment of a block is shown in Fig. 5. The uranium-bismuth fuel is contained in the vertical holes and the power-plant working fluid is heated as it passes through the horizontal holes. Four blocks are cemented together with vertical fuel holes in alignment and sixteen of these groups are stacked together to form the 4-ft-cube reactor core as shown in Fig. 6. The liquid fuel can be circulated through the core at a low rate sufficient for processing via graphite tail

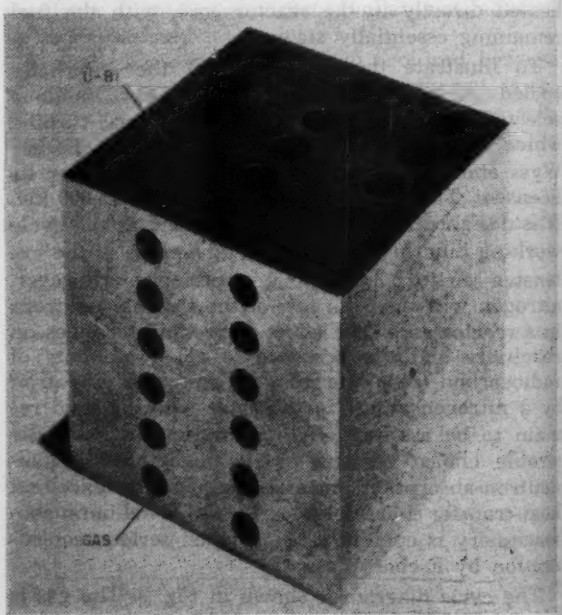


Figure 5. Section of a graphite core block.

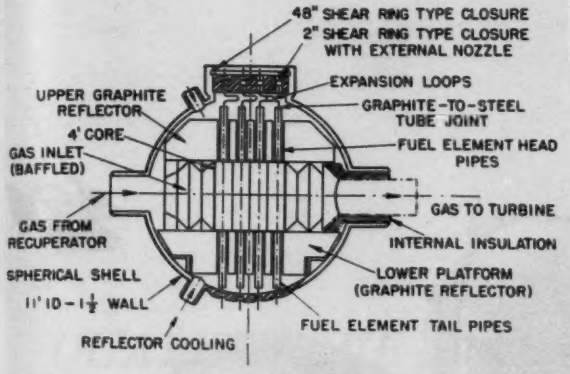


Figure 6. An internally cooled liquid-metal-fuel reactor.

pieces cemented to the ends of each group of blocks. One end of each tail piece is cored and cemented to the group of graphite blocks in order to gather and distribute the fuel. A graphite-to-metal tube joint is made at the outer end of each tail piece so that the fuel can enter and leave the reactor vessel through metal tubes.

The core can be surrounded by either a reflector or a breeding blanket, depending upon the application. For breeding applications, cross-drilled graphite blocks similar to the core subassemblies would be used. Thorium-bismuth slurry, which is being developed by BNL as a breeder fluid, would be in vertical holes. A portion of the power-plant working fluid would be diverted through appropriate horizontal holes, whether or not the reflector contained breeding fluid.

MATERIALS OF CONSTRUCTION

The success of a liquid-metal-fueled reactor as the heat source for a closed-cycle gas-turbine power plant will depend primarily on the development of a suitable container material for uranium bismuth at the required temperatures. In both the internally-cooled and externally-cooled arrangement, the container material must not react with the uranium bismuth and it must prevent diffusion of fission products into the power-plant working fluid.

Brookhaven is currently developing container materials for use at 1050° F in the steam plant mentioned previously. In addition to uranium, there are several metals which are soluble in bismuth. They range from iron at a few ppm to nickel, copper, aluminum, and magnesium at several per cent. Materials which appear to be practically insoluble in bismuth are beryllium, molybdenum, niobium, tantalum, and tungsten. It has been found that the addition of soluble inhibitors, such as zirconium, to a uranium-bismuth low-alloy-steel system at 1050° F can prevent corrosion by forming a protective zirconium nitride layer on the steel. Work on uranium-bismuth-graphite systems at 1800° F has shown that zirconium also forms a layer of zirconium carbide on graphite to prevent reaction between uranium and carbon.

For the externally cooled arrangement we do not yet know whether the inhibiting layer will be satisfactory on a heat-exchanger-tube material that has good mechanical properties at 1500° F. An alternative approach may be cladding the bismuth side of the tubes with one of the insoluble metals such as molybdenum or tantalum. In the internally-cooled arrangement, it has not yet been determined whether graphite will prevent the diffusion of fission products from uranium bismuth into the gas. It is hoped that certain surface-impregnation techniques will effectively prevent fission-product diffusion.

ADVANTAGES

The potential advantage of the nuclear power plant described herein is in the combination of a promising nuclear heat source with the closed-cycle gas turbine. The closed-cycle gas-turbine unit will be capable of high-temperature operation, and therefore will have a high thermal efficiency, through the use of an inert-gas working fluid. Equipment size will be moderate because of the elevated-pressure levels. The liquid-metal-fuel reactor offers a promising high-temperature heat source for the closed-cycle gas turbine, pending the development of suitable container materials for the fuel. The present effort on LMFR at the Brookhaven National Laboratory is on the fundamental problems of the uranium-bismuth fuel as applied to a steam-turbine system. However, there will be some common areas in which useful information for the gas-turbine system also should be obtained.

It is our hope that the LMFR closed-cycle gas-turbine power plant will be sufficiently attractive to those interested in the nuclear-power field to warrant further study.

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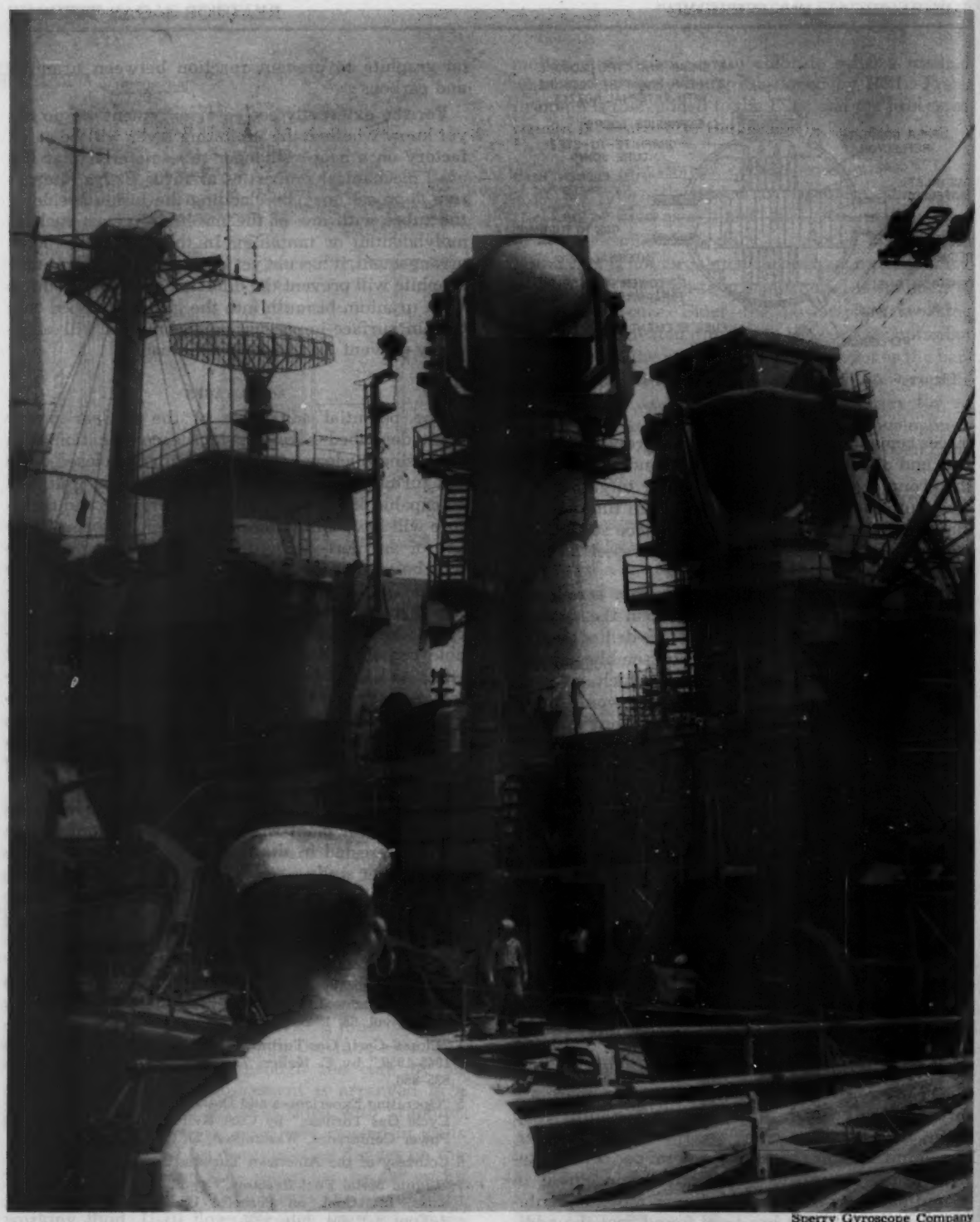

Sperry Gyroscope Company

Resembling gigantic searchlights, massive, turret-like structures aboard the Navy's missile ship CANBERRA have been identified as super-radar antennae for guidance of Terrier missiles. Developed for the Navy by Sperry Gyroscope Company, the long-range, high-altitude missile guidance radar systems came into fleet use only after years of successful tests. The two SPQ-5 systems aboard the CANBERRA combine many automatic radar functions in each unit. They include flexible modes of scanning the air space many miles beyond the horizon. Individual targets can be selected from close-flying groups and tracked at great distances while the missiles are launched and guided with "extreme accuracy."

COMMANDER CHARLES W. HARRISON, JR., USN

QUALITATIVE ANALYSIS OF LOOP ANTENNA BEHAVIOR IN LINEARLY AND ELLIPTICALLY POLARIZED ELECTRIC FIELDS

THE AUTHOR

attended the U. S. Naval Academy Preparatory School, the U. S. Coast Guard Academy and the University of Virginia, where in 1939 he received the S.B. degree in Engineering and in 1940 the degree of Electrical Engineer. In 1942 he was graduated with the S.M. degree in Communication Engineering, from Cruft Laboratory, Harvard University, and that summer completed the Navy Course in Radar Engineering at Massachusetts Institute of Technology. Subsequently for several years he was engaged in lecturing to officers of the Armed Forces assigned to the radar schools at Harvard and Princeton Universities. He has had four tours of duty in the Electronics Design and Development Division, Bureau of Ships; two at the U.S. Naval Research Laboratory; one at the Signal Corps Engineering Laboratories (Evans Signal Laboratory); and one at the Philadelphia Naval Shipyard. His experience includes amateur, naval and broadcasting operation. In 1951 Commander Harrison was selected for training in Advanced Science at Harvard University under sponsorship of the Office of Naval Research. This program led to the M. Eng. degree in 1952 and Ph.D. degree in Applied Physics in 1954. Commander Harrison is presently Electronics Officer on the Staff of Commander Operational Development Force. He is a member of several societies and associations, including the Harvard Chapter of the Society of Sigma Xi.

Summary: The measurement of the magnetic field associated with a linearly or elliptically polarized electric field, using a small loop, or magnetic probe, is discussed. It is shown that in general a loop will not measure the magnetic field faithfully because the sensing element responds to the antenna modes as well as the transmission line mode excited in the loop structure by the incident electromagnetic field. A special shielded loop with two gaps was invented to eliminate or reduce the effect of the antenna modes. It is anticipated that this device will be found useful in the field of direction finding.

I. INTRODUCTION

For many years loop antennas of rectangular or circular configuration have been employed for direction finding purposes. In operation, the plane of the loop is oriented vertically with respect to the surface of the earth, and the load impedance (or sensing element) is connected symmetrically in the loop at the top or bottom of the structure. This device may be used to measure the magnetic field associated with a vertically polarized electric field, provided complete structural symmetry obtains and there are no asymmetrically placed conductors or dielectrics in the vicinity of the loop. If the electric or magnetic field is elliptically polarized the correct bearing of a distant radio station cannot be obtained using a conventional loop. This phenomenon was termed "night effect" in the early days of direction finding technology.

The primary purpose of the present paper is to discuss, in a qualitative yet electromagnetically correct way, some of the properties of several small loop types for measuring the linearly polarized magnetic field associated with an elliptically polarized electric

field. A field of this description exists, for example, in the vicinity of a quarter-wave vertical antenna used for transmitting.

II. FIELD DEFINITIONS

The simplest case of an elliptically polarized field obtains if both the magnitude and direction of the field vary periodically in a fixed plane. If the field varies periodically in magnitude, but is always directed along a fixed line, it is said to be linearly polarized. If the field vector is linearly polarized along an axis perpendicular to the surface of the earth, it is said to be vertically polarized; if it is parallel to the surface of the earth, it is horizontally polarized.

The electric field at a point in the vicinity of a dipole antenna is elliptically polarized in the plane containing the point and the dipole. Since complete rotational symmetry exists, any such plane is typical. The associated magnetic field is linearly polarized, and is directed normal to this plane. At a considerable distance from a vertical radiator the vertically polarized electric field associated with the ground wave (if one exists) when added vectorially to the electric wave (s) reflected from the ionosphere, leads to a composite electric field which is generally elliptically polarized, but the plane of polarization is not fixed. Under these circumstances the associated magnetic field is also elliptically polarized and is simply the vector sum of two or more linearly polarized magnetic fields. It is to be understood, then, that under certain conditions an elliptically polarized electric field may have an associated linearly or elliptically polarized magnetic field.

III. ANALYSIS OF SIMPLE UNSHIELDED LOOP IN A LINEARLY POLARIZED ELECTRIC FIELD

Consider a simple retangular loop with load impedance Z depicted by Figure 1. Let the loop be oriented in such a way in space that the linearly polarized electric field E_v is precisely parallel to the vertical members of the loop. The electric field acting on the left and right vertical sides may be written:

$$E_{vl}=\tfrac{1}{2}\left\{E_{vl}+E_{vr}\right\}+\tfrac{1}{2}\left\{E_{vl}-E_{vr}\right\} \quad \ldots\ldots (1)$$

$$E_{vr}=\tfrac{1}{2}\left\{E_{vr}+E_{vl}\right\}+\tfrac{1}{2}\left\{E_{vr}-E_{vl}\right\}$$

$$=\tfrac{1}{2}\left\{E_{vl}+E_{vr}\right\}-\tfrac{1}{2}\left\{E_{vl}-E_{vr}\right\} \quad \ldots\ldots (2)$$

If

$$\left.\begin{aligned} E_{vs}&=\tfrac{1}{2}\left\{E_{vr}+E_{vl}\right\} \\ \text{and} \\ E_{va}&=\tfrac{1}{2}\left\{E_{vr}-E_{vl}\right\} \end{aligned}\right\} \quad \ldots\ldots (3)$$

then (1) and (2) become

$$\left.\begin{aligned} E_{vl}&= E_{vs}+E_{va} \\ \text{and} \\ E_{vr}&= E_{vs}-E_{va} \end{aligned}\right\} \quad \ldots\ldots (4)$$

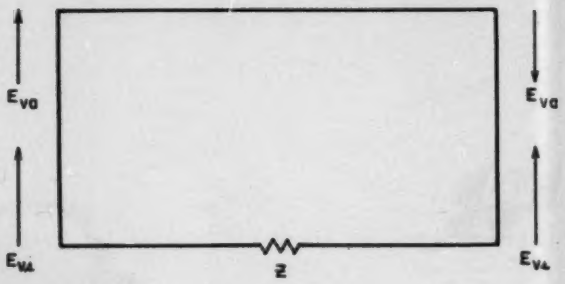

Figure 1.

This procedure has split the total electric field acting on the two vertical sides of the loop into symmetrical (co-directional) and anti-symmetrical (bi-directional components. Account is taken of the fact that E_{vl} is not equal to E_{vr} in either amplitude or phase. The subscripts s and a in (3) and (4) distinguish symmetrical and anti-symmetrical field components, respectively.

One of the relations between the electric field E and magnetic field B is

$$\text{Curl } E=-\frac{\delta B}{\delta t} \quad \ldots\ldots (5)$$

Stokes' theorem states that

$$\oint E : dl=\int_{\Sigma} \text{curl } E \cdot d\sigma \quad \ldots\ldots (6)$$

In words, the integral of the normal component of the curl of the continuous vector E over a surface Σ is equal to the line integral of the tangential component of E around the boundary of the surface. The direction of the line integration must be such that the right-hand screw convention is satisfied with respect to the normal to the surface.

Substituting (5) into (6),

$$\int_{\Sigma} \text{curl } E \cdot d\sigma=\oint E \cdot dl=-\frac{\delta}{\delta t}\int_{\Sigma} B \cdot d\sigma \quad \ldots\ldots (7)$$

Thus the circulation of the E vector around any closed contour in which E is continuous is equal to the negative time rate of change of the total normal flux B across any cap surface bounded by the contour. Applied to the present problem, equation (7) says that if one integrates the tangential component of the electric field around the boundary of the loop, one obtains the time rate of change of the normal component of magnetic flux B linking the loop. The magnetic field H may be obtained from the relation

$$B=\mu_o H \quad \ldots\ldots (8)$$

where if B is measured in $\frac{\text{volt-second}}{\text{square meter}}$ and H in $\frac{\text{ampere}}{\text{meter}}$, μ_o is $4\pi\times10^{-7}\frac{\text{henry}}{\text{meter}}$.

Applying (7) to the loop under discussion, one notes that E_{vs} contributes nothing to the line integral, and therefore the magnetic field linking the loop which induces a voltage in the loop conductor does

not depend on this component of electric field. E_{va} contributes to the magnetic induction, and one may say that the magnetic field (for sinusoidal waves) is proportional to the differential electric field. The field E_{va} is effective in setting up a circulatory current in the loop, which causes a voltage to be developed across Z. It is desirable to call this circulatory current a transmission line current. Currents are induced in the loop by the field E_{vs} acting on both sides of the loop. These currents may be called antenna currents because they are co-directional. The important thing to note is that these currents vanish at Z, i.e., do not contribute to the voltage drop across Z. Both sides of Z are charged to the *same* potential by the action of E_{vs}, moment by moment. When the charge concentration is a maximum at Z due to the antenna mode, the charge concentration at the center of the top horizontal member of the loop is also a maximum, but is of opposite sign.

It should be clear, from the above discussion, that a loop may be used to measure the B field associated with a linearly polarized E field provided the sensing element Z is symmetrically connected within the loop, and the vertical sides of the loop lie in an equiphase wave front.

IV. ANALYSIS OF SIMPLE UNSHIELDED LOOP IN AN ELLIPTICALLY POLARIZED ELECTRIC FIELD

For the purpose of explaining how an unshielded loop, or magnetic probe, responds in an elliptically polarized electric field, it will be supposed that one desires to measure the magnetic field in the vicinity of a thin vertical radiator approximately one quarter wavelength in height. It is assumed that the earth is perfectly conducting and that the current along the antenna is sinusoidally distributed. Under these circumstances the near zone electromagnetic field may be described in terms of mathematical surfaces of simple geometric shape on all points of which a suitably chosen component of the electric or magnetic field has the same phase. In the present instance the equiphase surfaces are all ellipsoids of revolution with the free end of the antenna and its image as foci. On each ellipsoid drawn around these foci, the complete electromagnetic field consists of three mutually perpendicular components, two of the electric vector and one of the magnetic vector. The two components of the electric vector are a component E_ε tangent to an ellipse that when rotated about the antenna as axis forms an equiphase ellipsoid of revolution and a component E_h perpendicular to this ellipse (tangent to an orthogonal hyperbola). The entire magnetic field is represented by H_ϕ. It is tangent to circles around the axis of the antenna, and thus tangent to the same ellipsoids of revolution as E_ε, but in a direction perpendicular to E_ε. The components E_ε and H_ϕ at any point are in phase. The component E_h lags E_ε at the same point in space by one quarter period in time. All three field components may be expressed simply in mathematical terms in confocal (ellipsoidal hyperboloidal) coordinates.

Figure 2 portrays a loop, with load Z in the elliptically polarized electric field developed by a quarter wave vertical radiator. In order to have the sides of the loop tangent to the E_ε and E_h field components, it is distorted somewhat from the conventional rectangular shape. One now writes the equations paralleling (1) to (4) inclusive. The result is:

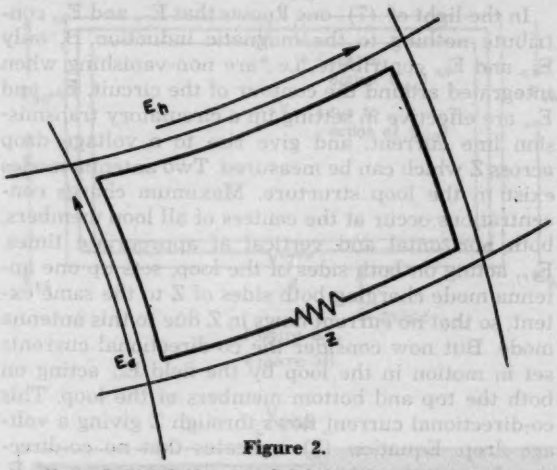

Figure 2.

$$\left.\begin{aligned} E_{\varepsilon l} &= E_{\varepsilon s} + E_{\varepsilon a} \\ E_{\varepsilon r} &= E_{\varepsilon s} - E_{\varepsilon a} \end{aligned}\right\} \quad \ldots\ldots (9)$$

where

$$E_{\varepsilon s} = \tfrac{1}{2}\left\{E_{\varepsilon l} + E_{\varepsilon r}\right\}$$

and

$$E_{\varepsilon a} = \tfrac{1}{2}\left\{E_{\varepsilon l} - E_{\varepsilon r}\right\}$$

Also,

$$\left.\begin{aligned} E_{ht} &= E_{hs} + E_{ha} \\ E_{hb} &= E_{hs} - E_{ha} \end{aligned}\right\} \quad \ldots\ldots (10)$$

with

$$E_{hs} = \tfrac{1}{2}\left\{E_{ht} + E_{hb}\right\}$$

$$E_{ha} = \tfrac{1}{2}\left\{E_{ht} - E_{hb}\right\}$$

In (9) and (10) the subscripts l, r, t, b refer to left, right, top and bottom of the loop, respectively.

Figure 3 shows the effective fields acting on the loop.

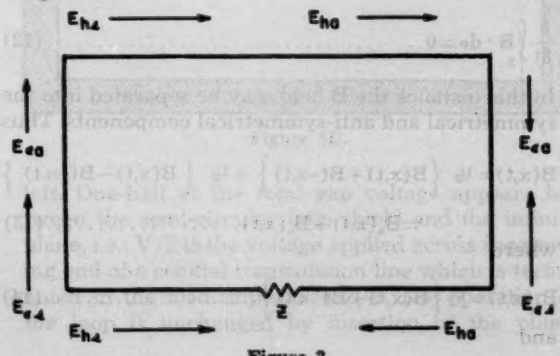

Figure 3.

In the light of (7), one knows that E_{ϵ_s} and E_{h_s} contribute nothing to the magnetic induction B, only E_{ϵ_a} and E_{h_a} contribute, i.e., are non-vanishing when integrated around the contour of the circuit. E_{ϵ_a} and E_{h_a} are effective in setting up a circulatory transmission line current, and give rise to a voltage drop across Z which can be measured. Two antenna modes exist in the loop structure. Maximum charge concentrations occur at the centers of all loop members, both horizontal and vertical at appropriate times. E_{ϵ_s}, acting on both sides of the loop, sets up one antenna mode charging both sides of Z to the same extent, so that no current flows in Z due to this antenna mode. But now consider the co-directional currents set in motion in the loop by the field E_{h_s} acting on both the top and bottom members of the loop. This co-directional current flows through Z giving a voltage drop. Equation (7) indicates that no co-directional currents enter into the determination of B. Therefore, the voltage read across Z does not correspond to B, so if one uses a loop to measure B, one has measured it incorrectly. It should be observed that Z cannot be placed *anywhere* in the loop structure to avoid this difficulty. This result leads to the inescapable conclusion that an ordinary unshielded one turn loop probe cannot be used to measure the linearly polarized magnetic field associated with an elliptically polarized electric field, unless the antenna currents flowing in the loop are small compared to the transmission line current.

V. OPERATION OF A COMPLETELY SHIELDED LOOP

Figure 4 illustrates a completely shielded rectangular loop consisting essentially of a re-entrant coaxial cable with load impedance Z connected in series with the center conductor. The original of a rectangular coordinate system is located at the geometrical center of the loop. The bottom of the loop is parallel to the OX axis. The incident electric field is parallel to the OY axis. Both the loop and electric field lie in the XY plane.

It is assumed that the coaxial shield is perfectly conducting. The tangential component of E is then zero along the surface of the shield. From (7),

$$\oint \mathbf{E}\cdot d\mathbf{l}=0 \qquad (11)$$

or

$$\frac{\delta}{\delta t}\int_{\Sigma}\mathbf{B}\cdot d\sigma=0 \qquad (12)$$

In this instance the B field may be separated into the symmetrical and anti-symmetrical components. Thus

$$\mathbf{B}(x,t)=\tfrac{1}{2}\left\{\mathbf{B}(x,t)+\mathbf{B}(-x,t)\right\}+\tfrac{1}{2}\left\{\mathbf{B}(x,t)-\mathbf{B}(-x,t)\right\}$$
$$=\mathbf{B}_s(x,t)+\mathbf{B}_a(x,t) \qquad (13)$$

where

$$\mathbf{B}_s(x,t)=\tfrac{1}{2}\left\{\mathbf{B}(x,t)+\mathbf{B}(-x,t)\right\} \qquad (14)$$

and

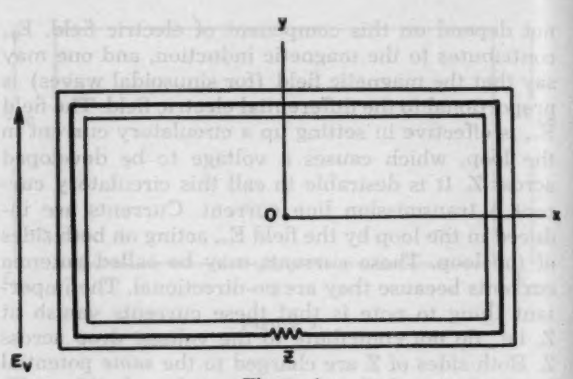

Figure 4.

$$\mathbf{B}_a(x,t)=\tfrac{1}{2}\left\{\mathbf{B}(x,t)-\mathbf{B}(-x,t)\right\} \qquad (15)$$

The symmetrical component of the B field is B_s; the anti-symmetrical component is B_a.

By definition,

$$\mathbf{B}_s(x,t)=\mathbf{B}_s(-x,t) \qquad (16)$$
$$\mathbf{B}_a(x,t)=-\mathbf{B}_a(-x,t) \qquad (17)$$

If the current flow in the transmission line mode is directed counter-clockwise around the shield, for example, an application of the right-hand rule reveals that the magnetic flux associated with this mode is directed parallel to the positive z axis, i.e., out of the paper at all points within the loop. This component of the total B field satisfies the symmetry condition (16) and is therefore called the B_s field. By a similar argument it can be seen that the magnetic flux associated with the antenna mode satisfies symmetry condition (17) and is the B_a component of the total magnetic field B.

From (12), using (13)

$$\frac{\delta}{\delta t}\int_{\Sigma}\mathbf{B}_s(x,t)d\sigma=-\frac{\delta}{\delta t}\int_{\Sigma}\mathbf{B}_a(x,t)d\sigma \qquad (18)$$

Because of symmetry condition (17), the right side of (18) is zero. Accordingly,

$$-\frac{\delta}{\delta t}\int_{\Sigma}\mathbf{B}_s(x,t)d\sigma=0 \qquad (19)$$

Expression (19) may be identified immediately as a more general form of the engineering formula

$$e=-N\frac{\delta\phi}{\delta t} \qquad (20)$$

This relation is used to calculate the voltage induced in a small coil of N turns by a magnetic field which changes with time. ϕ is defined by

$$\phi=\int_{\Sigma}\mathbf{B}_a(x,t)d\sigma \qquad (21)$$

On comparing (19) and (20) it is evident that the voltage induced in the center conductor of the shielded loop shown in Figure 4 is zero. Moreover, one may conclude that the B_s is precisely zero at every point within the loop bounded by the shield. If B_s is

essentially constant with respect to the space coordinates, i.e., the dimensions of the loop are small in terms of the wavelength,

$$\phi = B_s(t) \int_{\Sigma} d\sigma = B_s(t)\Sigma \quad \ldots\ldots (22)$$

With the aid of (22), (20) may be written in the form

$$\Sigma \frac{\delta B_s(t)}{\delta t} = 0 \quad \ldots\ldots (23)$$

for N=1. This requires B_s to be a constant, or zero. If a magnetostatic field links a loop which is fixed in space, no voltage is induced in the loop. But it is manifestly impossible for a radio station employing a vertical radiator to maintain a magnetic field invariant in time at all points in space!

One must not make the mistake of assuming that B_s is zero at all points within the loop. As much flux links the loop in one direction as in the other for the antenna mode.

There is no reason to believe that the analysis given here covering the behavior of a completely shielded loop in a linearly polarized field cannot be generalized to other loop shapes and more complicated incident fields with the same results. No voltage can be induced in the center conductor of a completely shielded loop, and therefore, no voltage is developed across the load impedance Z due to the action of the electromagnetic field in the vicinity of the loop. This statement is based on the assumption that the operating frequency is sufficiently high so that field penetration into the highly conducting shield is not significant.

VI. ANALYSIS OF A SHIELDED LOOP WITH GAP IN A LINEARLY POLARIZED ELECTRIC FIELD PARALLEL TO THE VERTICAL SIDES OF THE LOOP

A shielded loop consisting of shield with gap, one turn of wire with load insulated from the shield is shown in Figure 5A. The incident electric field E_v is represented by the symmetrical component E_{vs} and by the anti-symmetrical component E_{va}. The E_{vs} field sets up the antenna mode, which charges the gap with charge of the same sign moment by moment. The E_{va} component, however, charges the gap positive on one side and negative on the other, cyclically. Thus a voltage appears across the gap. For a perfectly conducting shield,

$$\oint E \cdot dl = V_{gap} = \int E_{gap} \cdot d\delta \quad \ldots\ldots (24)$$

where δ is the gap width, E_{gap} is the electric field across the gap, and V_{gap} is the voltage set up across the gap by the action of E_{va}. V_{gap} drives the load through two coaxial transmission lines connected in series.

This may be seen by referring to Figure 5B. Here a perfectly conducting infinite plane bisects the loop symmetrically. The semicircular loop to the right of the plane is the mirror image of the circuit to the left. One-half of the total gap voltage appears between the semi-circular loop shield and the infinite plane, i.e., V/2 is the voltage applied across the sending end of a coaxial transmission line which is terminated in the load impedance Z/2. The operation of the loop is unchanged by insertion of the plane.

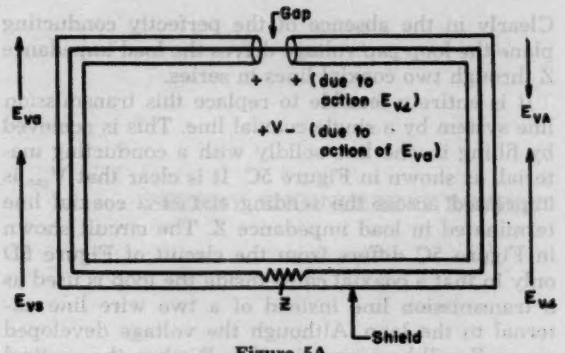

Figure 5A.

Figure 5B.

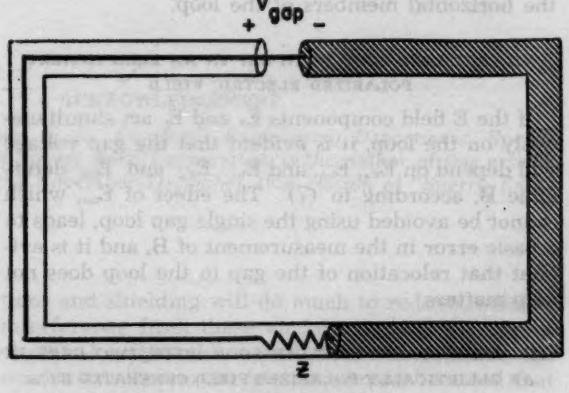

Figure 5C.

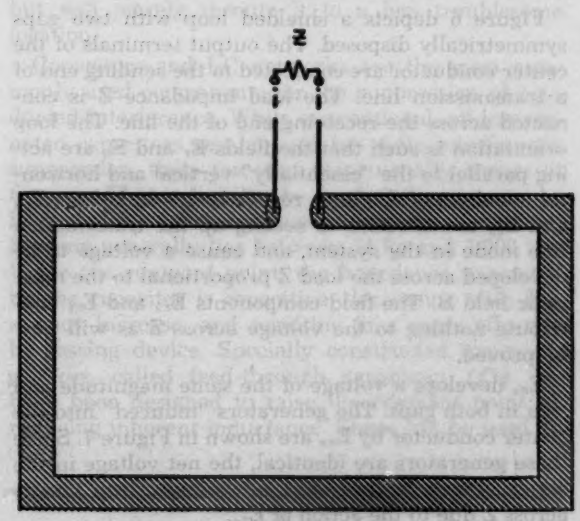

Figure 5D.

Clearly in the absence of the perfectly conducting plane the loop gap voltage drives the load impedance Z through two coaxial lines in series.

It is entirely feasible to replace this transmission line system by a single coaxial line. This is achieved by filling in one line solidly with a conducting material, as shown in Figure 5C. It is clear that V_{gap} is impressed across the sending end of a coaxial line terminated in load impedance Z. The circuit shown in Figure 5C differs from the circuit of Figure 5D only in that a coaxial cable inside the loop is used as a transmission line instead of a two wire line external to the loop. Although the voltage developed across Z will be proportional to B when the vertical sides of the loop lie in a wave front of constant phase, this is not true where there is a component of E along the horizontal members of the loop.

VII. SHIELDED LOOP WITH GAP IN AN ELLIPTICALLY POLARIZED ELECTRIC FIELD

If the E field components E_v and E_h act simultaneously on the loop, it is evident that the gap voltage will depend on E_{va}, E_{ha}, and E_{hs}. E_{vs} and E_{hs} determine B, according to (7). The effect of E_{hs}, which cannot be avoided using the single gap loop, leads to a basic error in the measurement of B, and it is evident that relocation of the gap in the loop does not help matters.

VIII. ANALYSIS OF SHIELDED LOOP WITH TWO GAPS IN AN ELLIPTICALLY POLARIZED FIELD GENERATED BY A QUARTER-WAVE VERTICAL RADIATOR*

Figure 6 depicts a shielded loop with two gaps symmetrically disposed. The output terminals of the center conductor are connected to the sending end of a transmission line. The load impedance Z is connected across the receiving end of the line. The loop orientation is such that the fields E_v and E_h are acting parallel to the "essentially" vertical and horizontal members of the loop, respectively. As before, E_{va} and E_{ha} are effective in setting up the transmission line mode in the system, and cause a voltage to be developed across the load Z proportional to the magnetic field B. The field components E_{vs} and E_{hs} contribute nothing to the voltage across Z as will now be proved.

E_{vs} develops a voltage of the same magnitude and sign in both gaps. The generators "induced" into the center conductor by E_{vs} are shown in Figure 7. Since these generators are identical, the net voltage in the series circuit is zero, and no voltage drop occurs across Z due to the action of E_{vs}.

Now consider the action of E_{hs}. This field component induces co-directional currents which charge each side of a gap (either the right or the left gap) to the same potential. Thus the gap voltage is zero due to the action of E_{hs}, and no current flows in the center conductor from this cause. The action of the two gap loop is to eliminate the deleterious effect of

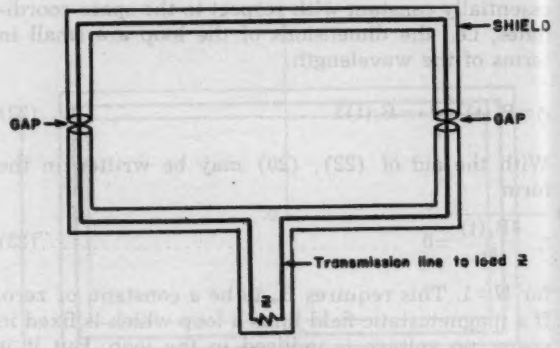

Figure 6.

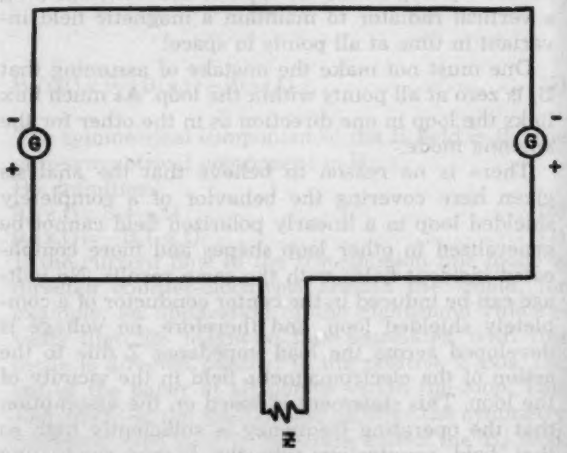

Figure 7.

the antenna modes. The magnetic field associated with the elliptically polarized electric field considered here will be correctly measured for the particular loop orientation chosen.

Many ramifications in shielded loop design suggest themselves. For example, a shielded loop with one gap might be constructed inside a two gap shield. For this arrangement it is evident that the load impedance Z may be located anywhere in the innermost conductor without obtaining an error in the field measurement even when the loop is activated by an elliptically polarized E-field.

There should be a vast difference in the effectiveness of a two gap shielded loop over the conventional single gap shielded loop for direction finding applications, in the air, afloat and ashore, when the incident field is a synthesis of several linearly polarized fields.

CONCLUSION

It is not a simple matter to measure the magnetic field associated with an elliptically polarized field using a loop antenna. It appears that under many circumstances false results will be obtained.

The magnitude of the error introduced into magnetic field measurements when the sensing element measures currents in the antenna as well as transmission line modes, has not yet been determined.

*An application has been filed for a patent on this device.

"SPERRY ENGINEERING REVIEW"

RADIO INTERFERENCE FILTERS

ACKNOWLEDGEMENT

Mr. John W. Trinkaus, of the Standards Engineering Department, Sperry Gyroscope Division of Sperry Rand Corporation, is the author of this article. It was published in the November-December 1956 edition of "Sperry Engineering Review."

INTRODUCTION

As MILITARY equipment becomes more complex, within constantly decreasing size limitations, electronic devices are used in closer proximity. This fact, coupled with the large number of electronic devices of increasingly high power levels and receiver sensitivity used per equipment, accentuates the problem of spurious radiation and susceptibility. This situation, most common in the form of mutual disturbance in radar and communications equipment, is termed interference.

Interference is any unwanted signal present in, or adjacent to, a piece of equipment. Many components within a system can serve as generators of this unwanted potential (e.g., relays, switches, motors and magnetrons). Power leads can transmit these signals to other parts of the system, and radiation from the power leads can couple the unwanted potential into adjacent signal leads. Unless effective suppression methods are employed the entire system may become "infected," resulting in radiation of interference to the area adjacent to the device. The unwanted condition is represented by the introduction of this interference on the information leads of an adjacent piece of communication equipment in such magnitude that the desired signal becomes unintelligible.

Since most radar systems are composed of black boxes interconnected by leads, the main problem is either to contain the interference within these boxes or to suppress it at its source. Proper suppression of conducted interference will also result in a reduction of radiated interference. Physical design considerations and shielding will do much to reduce radiated interference from these enclosures, and the use of electrical suppression components will minimize the conducted noise in the leads. It should be noted that electrical suppression will not dissipate r-f energy, but will merely reroute it to a less troublesome location.

Capacitors and LC networks are the most commonly used components for the suppression of conducted interference. While conventional, oil-impregnated capacitors can be used for radio interference suppression, their resonant point usually occurs at five mc. This is low in the frequency range to be filtered. The radio frequency range that requires filtering generally lies between 14 kc and 1,000 mc. Up to the resonant point, the impedance presented by the capacitor is capacitive, decreasing with frequency increase, and resulting in a more effective by-passing device. Specially constructed paper capacitors, called feed-through capacitors (Fig. 1), have been designed to raise the resonant point by reducing inherent inductance. These can be used on

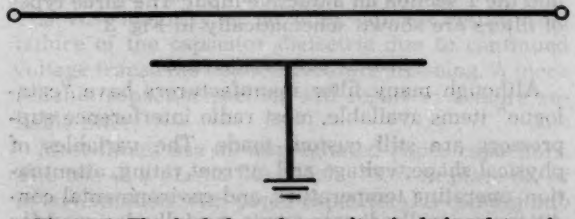

Figure 1. The feed-through capacitor is designed to raise the resonant point by reducing the inherent inductance.

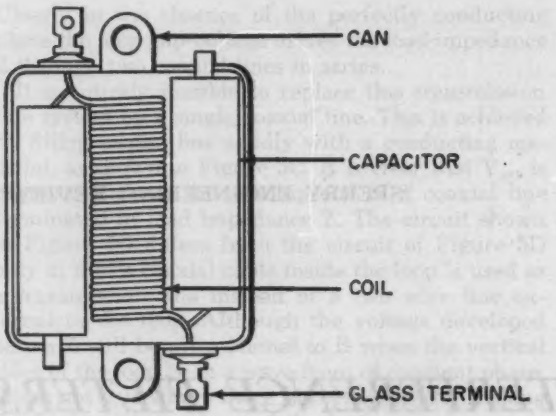

Figure 2. Illustration shows cutaway view of π-type filter which provides large attenuation for small size increase.

the high end of the r-f band (100 to 1,000 mc). Because their effectiveness is limited to higher frequencies, their application is also limited. Mica and ceramic materials may be used effectively, but are limited by their small capacitance values (in the $\mu\mu f$ range as compared to the μf range for paper capacitors). They find their chief use in the filtering of trigger circuits which generally contain relatively low noise levels. The LC network is effective over the widest frequency range, and offers a maximum of attenuation. It is the component which will be treated in detail in this paper.

The three most common types of radio interference filters are the *L* section, the *T* section and the π section. The π type filter (Fig. 2) is the most widely used because it provides greater attentuation for a small increase in size over the *L* and *T* types. However, the higher cost of the π type may not always be justified and, if lower attenuation limits can be tolerated, either the *L* or *T* section should be used. The *L* section generally presents a capacitive input and the *T* section an inductive input. The three types of filters are shown schematically in Fig. 3.

DESIGN CONSIDERATIONS

Although many filter manufacturers have "catalogue" items available, most radio interference suppressors are still custom made. The variables of physical shape, voltage and current rating, attentuation, operating temperature, and environmental conditions generally dictate a unit specially designed for a particular application. Therefore, as a custom made item, the filter's characteristics should be considered in its salient design features.

Physical Shape

Unfortunately, radio interference filters do not often receive careful attention until the equipment design is near completion. The space allotted or available for the filter is generally small, of irregular shape, and is often located so the effectiveness of the filter is reduced.

Allowing adequate space for the filter will insure a package that contains sufficient attenuation to reduce the equipment noise to the level provided for in applicable specifications. The smaller package requires smaller LC components and, consequently, provides less attenuation. Estimates of the expected noise levels should be made early in the design stages, and sufficient space should be allotted each component to supply the needed attenuation.

The allotment of an irregular space prevents the component manufacturer from using standard cans (containers normally used for the housing of capacitors). The use of a special fabricated can, in addition to increasing cost of the component and possibly restricting sources of supply, may prevent the best utilization of the available space by restricting capacitor and coil location within the container. Furthermore, the reliability of the component may be adversely affected.

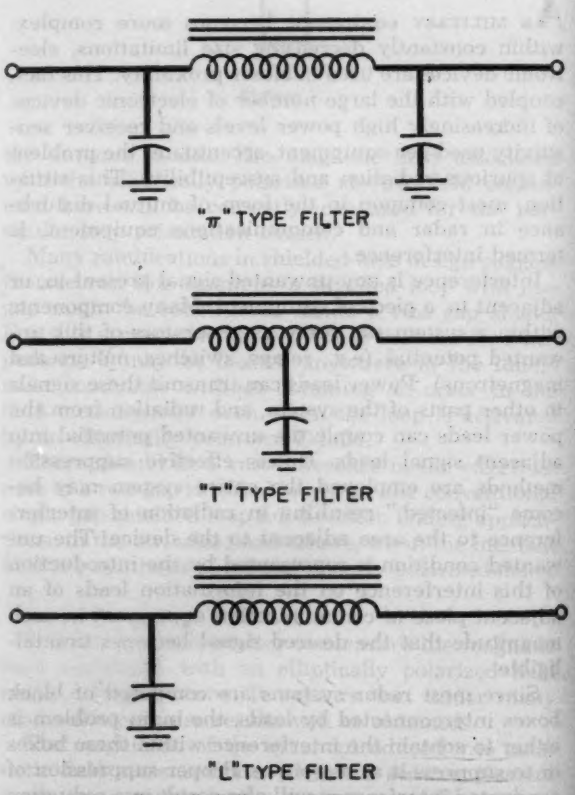

Figure 3. The "π", "T", and "L" type filter constructions are presented schematically in the illustration above.

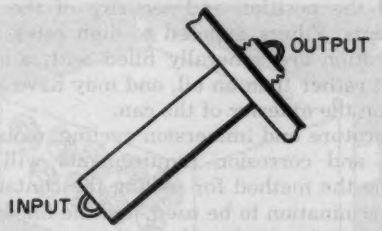

Figure 4. The bulkhead-mounted filter is best utilized by presence of a ground plane between the input and output.

Physical Location

For maximum filter efficiency, the external input terminal should be shielded from the output terminal. This will prevent noise radiation from coupling the filter between the "dirty" lead and the "clean" lead. It is best accomplished by positioning the filter so that a ground plane will be present between the input and output sides of a bulkhead-mounted suppressor (Fig. 4). If a wall is not available, a shielded cap over the output terminal and a shielded output lead may be used (Fig. 5). However, this latter unit is less efficient than the bulkhead-mounted type of suppressor.

In addition to the consideration of maximum filter efficiency in locating a filter, special care must be exercised in the location of a-c filters. The introduction of a capacitance between an a-c line and the frame of an ungrounded item of equipment may create a shock hazard unless the capacitance is limited to a value which will not pass a dangerously large current.

Electrical Rating

The electrical rating of a filter (i.e., the voltage and current to be handled) will largely determine the physical size of the resulting component. The inductance coil must be designed to use a wire size sufficient to handle the current load safely. Capacitor sections must be designed with voltage ratings high enough to withstand the potential to be applied across them (equal to the voltage ratings of the filters). Greater voltage potential requires a thicker dielectric and a larger filter. An a-c potential will necessitate use of a larger component, due to the heating effect of the frequency, and the permissible voltage stress on the capacitor dielectric will be reduced. The per cent increase in size will be a function of the a-c line frequency.

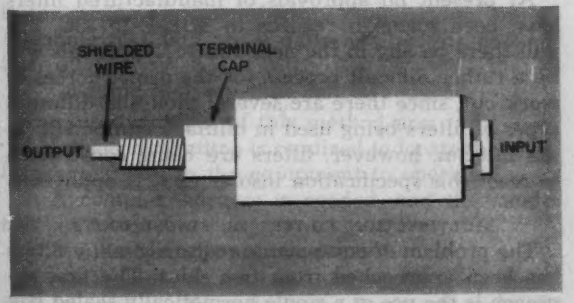

Figure 5. In the absence of a wall, a shielded output lead and shielded cap are required for a bulkhead suppressor.

Insertion Loss

The primary objective of any radio interference filter is attenuation of an unwanted signal. The amount of attenuation required is an additional variable which will determine the size of the resulting package. Increased attenuation requirements will necessitate correspondingly larger components.

The term attenuation generally is not used when referring to radio interference filters. The phrase insertion loss is more properly applied, since all db performance figures for a filter consider that the filter operates into a fixed 50 ohm resistive load. This point should always be kept in mind when the manufacturer's performance data for a filter are being evaluated. The figures do not represent the values that can be expected in the equipment unless the equivalent impedance that the filter sees is a pure 50 ohm resistance. Any other impedance will give a mismatch which may result in an insertion loss as high as 8 to 10 db less than the rated value.

The term insertion loss is generally qualified either as minimum insertion loss or as average insertion loss. Minimum insertion loss represents the poorest performance to be expected from any unit of a lot built within component limits. It also represents the low side of the generally accepted tolerance on the circuit parameters. Average insertion loss represents the mean value to be expected from the lot, and will generally run six db above the minimum insertion loss figures.

Voltage Drop

An additional factor to be considered in the evaluation of a radio interference filter is the voltage drop that can be expected in the line as a result of the insertion of this component. In the case of the d-c filter, the voltage drop can be computed and its acceptability evaluated if the resistance of the inductance coil and the current which will be drawn are known. In the case of the a-c filter, the problem is a little more complex. Based upon the impedance of the inductance coil and the phase angle of the current, a voltage rise instead of a voltage drop is entirely possible. Care must be exercised that the resulting voltage change, whether rise or fall, is compatible with the system.

Capacitor Sections

The weak link in any filter is the capacitor section. The vast majority of all filter failures result from failure of the capacitor dielectric due to continued voltage transients and temperature stressing. A more reliable capacitor section will result in a more reliable filter.

Most filters use oil-impregnated paper capacitors. The use of a plastic film, Mylar "C," in place of, or in combination with paper capacitors, is coming into popular usage. Mylar "C" offers higher insulation resistance than that available with oil impregnated

paper. Because the capacitive element is connected between the line and ground, higher insulation means less current leakage to ground, with a resultant power saving in a d-c system. Power losses on a-c systems are governed by the value of capacitance used. This capacitance value must be a compromise between the value required for the needed insertion loss and the loading that will be presented to the system. The current drawn on a-c systems is a function of the capacitance to ground and the power line frequency.

In an effort to minimize the size of radio interference filters, metallized paper capacitor sections have been used in some cases. They are not, however, generally recommended for filter usage for the following reasons:

1. The poor power factor resulting from this type of construction limits their use to d-c and low a-c applications (up to 400 cps). Poor power factor results in heat under a-c applications.
2. The poor internal termination of this type of capacitor may manifest itself as a malfunction (open section) under conditions of severe shock and vibration.
3. A minimum voltage and current must be maintained across the section in order to clear faults. The clearing of faults as they occur will represent lost power to the system.
4. Compared with oil impregnated paper, metallized paper capacitors exhibit poor insulation resistance, with high leakage current to ground.

If filters with metallized paper sections can be properly applied within the above limitations, they will provide considerable reduction in the space and weight required in an equipment needing interference suppression.

Inductors

Present methods for measuring insertion loss use a fixed 50 ohm resistance termination under conditions of no load. The insertion loss figures obtained under conditions of full load may be much lower than the no-load figures unless proper consideration is given to the coil core material. Materials which fully saturate under conditions of rated current should not be used. The saturation of the core will reduce the effective value of the inductance, and result in a reduction of the insertion loss.

Environmental Conditions

The remaining design considerations may be classified as environmental (i.e., the ability of the component to function satisfactorily under a given set of conditions).

The maximum ambient temperature (the temperature of the air immediately surrounding the filter) will determine the wire size used on the inductance coil. Also, it will determine the type of dielectric, the impregnant used for the capacitor sections, and the thickness of the dielectric.

Vibration and shock requirements are a consideration in the type of container selected, its mounting, and the position and security of the internal components. Filters exposed to high rates of shock and vibration are generally filled with a solid impregnant rather than an oil, and may have reinforcing fins on the exterior of the can.

Temperature and immersion cycling, moisture resistance, and corrosion requirements will largely determine the method for sealing the container, the type of termination to be used, and the finish.

The remaining, and perhaps the most important, environmental requirement is that of minimum life. The minimum life of a filter represents the number of hours a unit will operate satisfactorily under rated conditions and at the maximum ambient temperature. The term minimum is used again to indicate that all units of a lot should be capable of meeting this requirement. The term average represents three times the number of hours indicated as a minimum life.

The life of a filter is generally limited by the life of the capacitor sections. The combination of voltage potential, the heat generated in the inductance coil, and the ambient temperature will continually stress the dielectric until failure occurs. For a given temperature and voltage rating, the failure time is a function of the type of the dielectric.

Most filters are designed for a minimum life of 1,000 hours under rated conditions and maximum temperature. However, there is no assurance that all the units in a lot will function properly for that period. On the other hand, any reduction in either the temperature or the voltage will lengthen the life of the filter.

APPLICABLE MILITARY SPECIFICATION

Military specification MIL-F-15733C was developed for radio interference filters. It is a component specification and therefore does not govern the performance of the filter in a system. It does govern the ability of a filter to meet environmental conditions, and indicates the methods for measuring insertion loss (MIL-STD-220).

In addition to MIL-F-15733C, the Department of the Navy, Bureau of Ships, maintains a filter specification for its own use. This specification "MIL-F-18344A (Ships), Filters, Radio Interference, Naval Ship and Shore Use," is accompanied by a Military Qualified Products List (QPL-18344-2).

At present no approvals of manufactured filters have been made in regards to MIL-F-15733C, nor will there be any in the near future. Approvals will be a rather difficult process for the armed forces to work out, since there are several thousand different types of filters being used in military equipment. In the interim, however, filters are being constructed to meet this specification insofar as it is applicable.

MULTISECTION FILTERS VS. SINGLE UNITS

The problem of equipments requiring many filters has been approached from two sides. The first approach is the use of a single hermetically sealed box containing all the LC circuit parameters needed for

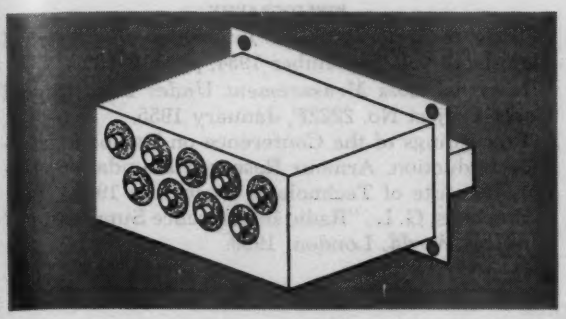

Figure 6. Input and output connections to the multi-section filter are solder-sealed terminals and an A-N connector.

filtering the equipment. Input to the container is usually accomplished by means of compression solder sealed terminals; the output, through a bulkhead, is generally by means of an A-N connector, as shown in Fig. 6. The advantages of this method of packaging are as follows:

1. Field replacement is comparatively easy, and the down time required to return the inoperative equipment to usage is short.

2. All power leads are routed to one point, passed through a black box, and leave the equipment through a single point.

3. A small saving in size and weight is effected.

The disadvantages of this method are as follows:

1. Failure of any capacitor section means failure of the entire unit, since replacement of circuit parts within the hermetic enclosure is not practical.

2. The reliability of this type of unit is greatly reduced, as compared to a single network, by the large number of capacitor sections involved. Multi-section filters are seldom properly evaluated, due to their individual applications. Also, they require special containers that increase cost and delivery time.

The second approach is the use of many single filters. Both input and output of each unit are accomplished by means of solder type terminals. The advantages of this method are:

1. Failure of one capacitor does not mean the loss of all filters in the system.

2. Reliability is increased, because only two capacitor sections are involved per component, and manufacturers have considerably more experience in the design and manufacture of individual units. Adequate test data are usually available to control their quality.

3. Cost and delivery time can be reduced.

The disadvantages of this method are:

1. Longer down time is required to locate the malfuction and return the equipment to operation.

2. A complex harness is needed, and the single exit point is lost.

3. Size and weight are greater.

A combination of the two methods, if space limitations permit, offers the user the most practical solution to this problem. Individual, standard components are located within an open framework to provide replacable units within a common enclosure. The output leads are brought to an A-N connector located on the frame to provide the single egress point, as shown in Fig. 7.

CONCLUSION

As military equipment becomes more complex, the number of associated electronic devices is increasing. The close proximity of these devices in an aircraft or on a naval vessel leads to the problem of mutual interference between armament equipment and communication equipment.

Proper design techniques and the proper location of component parts will do much to suppress radio interference. The principal r-f interference suppression component is the filter, or LC network combination. In the present state of the art, most radio interference filters are not standard items, but are custom made for an equipment.

The user should recognize some of the considerations that go into the design of a custom-made interference filter: the importance of the physical container and its location for obtaining maximum efficiency from the filter, the meaning of minimum insertion loss, the capacitor section as the limiting parameter in the life of the network, and governing environmental conditions.

A military specification, MIL-F-15733C, governs the ability of radio interference filters to meet environmental specifications. It defines standard test procedures. It does not, however, specify suppression performance in an equipment.

When more than one radio interference filter is needed per equipment enclosure, the use of many single units or a single multi-circuit hermetic container, should be carefully evaluated. The use of an open-type construction, with "standard" components, should be investigated as a possible compromise which will integrate the advantages of both methods.

Since the radio interference filter industry will offer a wide variety of solutions to a given suppression problem, as well as afford the possible alternate

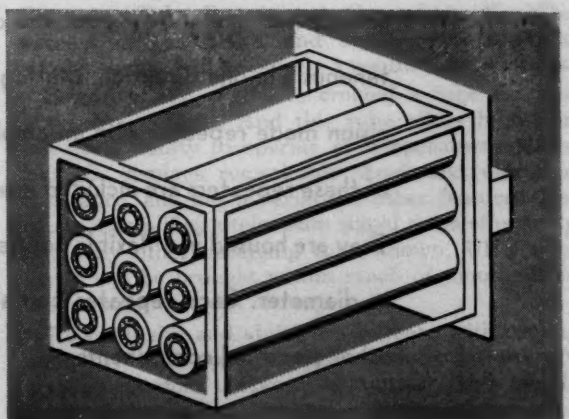

Figure 7. Open type construction of a multi-section filter shows termination of output leads in a single exit point.

of using "standard" components, the product designer cannot normally devote sufficient time to evaluate the field thoroughly. Therefore it is recommended that a suppression specialist be consulted in order to utilize the best approach for each application.

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A new static switching control system which accomplishes the control functions previously performed by contact making devices, such as relays, has recently been developed. The devices incorporated are encapsulated, have no moving parts, and employ conservatively rated sub-components. This greatly reduces wear, fatigue and other effects of environmental conditions. Static switching systems are useful where frequent or continuous operations are needed, or where complex systems or adverse environmental conditions exist. The new system represents a big step forward in the advancement of automation control.

The first physical voice link to be established between North America and Europe, a transatlantic telephone cable system, was opened to public service less than a year ago. The coaxial cable can carry 36 voices simultaneously in one direction. Making this cable possible is the intricate, precision made repeater with an amplification factor of 1,000,000. Fifty-one of these repeaters are included in each cable, spaced about 40 miles apart. They are housed in a flexible copper tube about 8 feet long and 1¾ inches in diameter. Each repeater contains three vacuum tubes and about 60 other electrical components.

"GENERAL ELECTRIC REVIEW"

NEW RESEARCH CONCEPTS SPARK MICROMINIATURE TUBE

ACKNOWLEDGEMENT

This staff article was published in the November, 1956 edition of "General Electric Review."

MAJOR scientific achievements today tend to resemble the harvest from an orchard cared for by a staff of highly specialized horticulturists. Often when a particular project bears fruit, the results are the efforts of many men. Such an approach not only draws upon the skills and knowledge of scientists in a variety of fields but also provides a means of conducting the long, complex, and expensive attempts to bring forth new knowledge that characterizes contemporary research.

Evolution of the 6BY4 microminiature vacuum tube—announced by General Electric about a year ago—excellently illustrates this method of operation. Significant research lies behind the tube's development: more than 15 years of progress in related designs and important discoveries by General Electric's Research Laboratory scientists in the fields of chemistry, metallurgy, ceramics, and electronic tubes and circuits. And to this basic work should be added manufacturing skill as well as the knowledge of engineers in other General Electric departments.

Though small in size, this vacuum tube also serves as an eloquent reminder that the individual is not completely eclipsed. Despite all the requisite coordination and collaboration, scientific achievements still reflect the individual scientist whose insight into a problem inspires and channels the efforts of his collaborators and stamps his mark upon the finished work.

In the research that led to the ceramic microwave tube, such a role was filled by two men: E. D. McArthur and James E. Beggs.

FATHERING THE TUBE

McArthur's concepts concerning the unity of circuit and tube elements in cavity-resonator systems led to his development of the new tube's revolutionary forerunner, the "lighthouse" tube, used in World War II radar. Manager of the Laboratory's electron tube research section for the past six years, he also participated in Beggs' development of the new microminiature-tube design. Beggs took existing concepts, added new ones, and developed new processes. In short, he fathered the tube.

Essential contributions also were made to the series of earlier tubes by the Company's Power Tube Department located in Schenectady, NY, and to the 6BY4's design and production techniques by the Receiving Tube Department, Owensboro, Ky. The success of the 6BY4 and subsequent tubes of similar design will be largely a result of their efforts.

Scientists and engineers created a tube the size of a pencil eraser. And this tube offers high-gain low-noise ability to operate at temperatures above 500° C, displays remarkable shock and vibration resistance, and has a variety of other features. Because it amplifies a television signal more effectively than any other receiving tube known, UHF television can be brought within reach of thousands of homes otherwise out of range.

Its small size and ability to dispense with cooling equipment also point to applications in jet aircraft, nuclear reactors, airborne computers, and mobile communications equipment as well as earth satellites and guided missiles.

A great quantity of groundwork prepared the

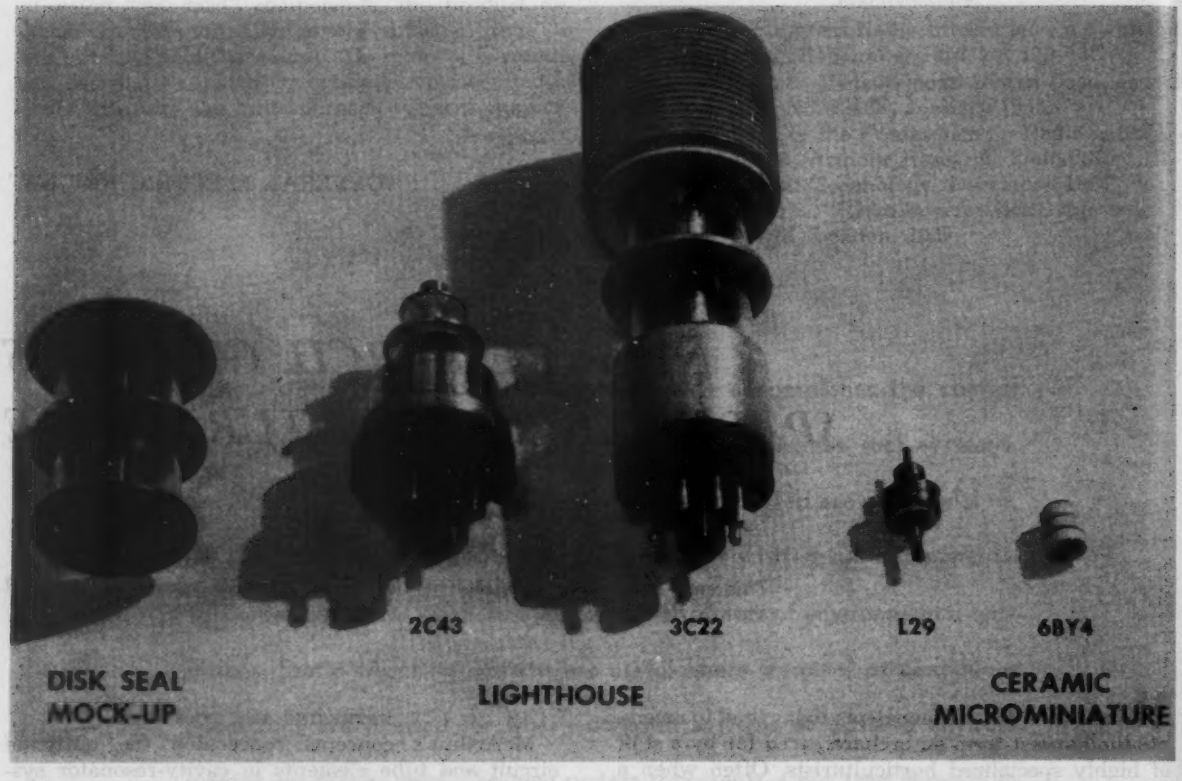

Figure 1. Ceramic Tube's Predecessors. From original disk-seal tube to ceramic tube represents more than 15 years of development.

way for the new development. Under the sponsorship of the U. S. Navy Bureau of Ships, the Research Laboratory set out in the 1940's to develop a rugged low-noise amplifier tube for applications at microwave frequencies. The Navy particularly wanted improved receivers to extend the range of early-warning radar stations and for an excellent reason. To identify a target on a radar screen, a pip must be discernible from the smaller irregularities in the trace caused by noise. Thus any reduction in noise makes the pip easier to distinguish. Reducing the noise factor of the receiver by one half would have the same effect as doubling the power of the transmitter. Doubling the transmitter power, say from 5 to 10 megawatts, might easily cost several hundred thousand dollars.

McArthur's combination of his cavity-resonator concept with a unique disk-seal design supplied the answer by making tubes virtually self-shielding. Together they made up the lighthouse tube (Figure 2).

As early as 1938, McArthur experimented with certain metallic enclosures of the pillbox type for use as filters, oscillators, or amplifiers. Although these cavity resonators had great potentialities for high-frequency applications, no tube then available enabled him to take full advantage of their potential. For maximum efficiency, these resonators have to be perfectly symmetrical. Because the electron tube used in conjunction with the resonator ideally forms its central core, the tube itself must also be symmetrical, unlike conventional tubes with the usual anode-grid-plate arrangement.

FORERUNNERS OF THE TUBE

McArthur's approach—finding a means for making the tube elements both symmetrical and integral with the resonant circuit—involved a radical change in viewpoint. It meant combining the electron tube and its attached circuit into a single system.

"The disk tube," says McArthur, "embodies the principle that in the microwave field we could no longer speak of tubes and circuits as two distinct entities."

The tube resulting from this concept shortly before World War II consists of a series of glass or ceramic cylinders closed at the ends by metal disks hermetically sealed at the circumference. Performing three functions, these disks 1) divide the tube into sections that coordinate with the corresponding resonant circuits; 2) contain or support the tube's electrodes; and 3) become—through the ring contacts at their periphery—part of the cavity-resona-

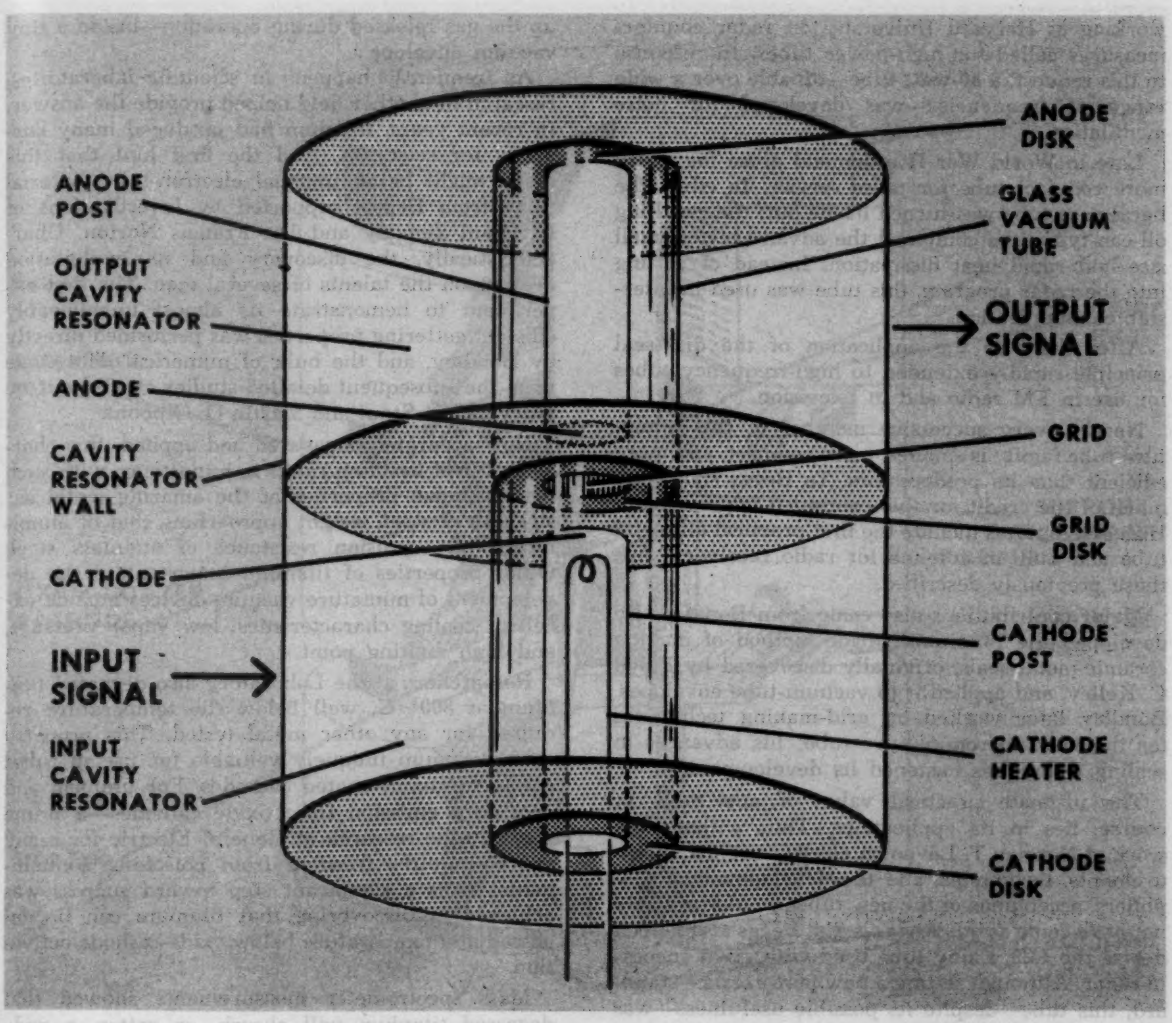

Figure 2. Basic Lighthouse Tube and forerunner of the microminiature ceramic tube was used in World War II radar. Its revolutionary concepts led to the development of the new tube.

tor's structure that surrounds them, thus making lead wires or prongs unnecessary.

The performance of the first disk-type tube, a transmitting tube operating at 600 megacycles, exceeded all expectations. The frequency was rapidly stepped up to 3000 megacycles. Ralph J. Bondley, associated with McArthur in this development, ingeniously contributed to the physical design and the details of manufacture. These largely influenced the immediate acceptance of the new tube.

Following the successful application of the disk-seal principle to transmitting tubes, the scientists immediately directed their attention toward developing a receiving tube that embodied the same principles. In his efforts, Beggs principally worked out the design details and the method of fabrication. An early model of the lighthouse tube, first used in a naval engagement at Guadalcanal, subsequently played an important role as a receiver preamplifier and as a local oscillator at a 200-megacycle frequency. It was also used with a Navy gun director at 700 megacycles.

Early in 1942 the Radiation Laboratory at Massachusetts Institute of Technology asked for a light, compact medium-power oscillator at 3000 megacycles for pulse service. A tube manufactured for use at 2-kw intermittent power and developed by Beggs met their need.

A combination of these two tubes in a small, simple device became the standard masthead radar unit for PT boats, subchasers, and other small craft. Subsequently modified by the Radiation Laboratory for the airborne gun director, out of this unit came the ARO (airborne range only) system.

Until 1943, efforts were concentrated on these models for radar service. At that time the groups

working at Harvard University on radar countermeasures called for high-power tubes. In response to this request, a 50-watt tube—tunable over a wide range of frequencies—was developed for noise modulation.

Late in World War II a demand arose for a still more compact tube for pulse service. In effect the lighthouse tube was turned inside out; the resulting oil-can-type tube combined the advantages of small size and rapid heat dissipation. Instead of getting into the radar program, this tube was used in intership communication.

After the war the application of the disk-seal principle rapidly extended to high-frequency tubes for use in FM radio and in television.

Nearly every successive member of this miniature-tube family is smaller, more compact, and more efficient than its predecessors. To Beggs should go much of the credit for this continued improvement. His contributions include the first practical all-metal tube and built-in antenna for radio receivers, plus those previously described.

Major contributions also came from Bondley. He developed the titanium-hydride method of making ceramic-metal seals, originally discovered by Floyd C. Kelley, and applied it to vacuum-tube envelopes. Bondley later worked on grid-making techniques for the new microminiature tube; his advances in sealing techniques hastened its development.

The ultimate practical value of any tube, of course, lies in its applications. Thus without the work of Norman T. Lavoo on electric circuits, measurements, techniques, and the development of amplifiers, acceptance of the new tubes would probably not have come as quickly as it did. Beggs also helped devise the L29, a tiny tube used with great success in radar. Although setting a new performance standard, this tube—despite its possible usefulness—was too expensive for application in low-priced electronic equipment.

A SUCCESSFUL SEARCH

Beggs thus began searching for a tube that could be mass-produced at low cost, yet offer high performance. Result: the new microminiature design.

The striking assortment of unique features incorporated into this type of tube was largely made possible by a combination of the three "products" of the Research Laboratory: new knowledge, materials, and processes.

New knowledge includes original and radical concepts of tube design, some dating from the work on the cavity resonator; new basic understanding of the causes of "noise" in electronic tubes; basic research on low-temperature cathodes with high electron emission; and the uncovering of some surprising fundamental facts about titanium—the wonder metal.

Part of the new knowledge resulted from Beggs' effort to solve the problem of "gettering"—sopping up the gas released during operation—inside a tiny vacuum envelope.

As frequently happens in scientific laboratories, research in another field helped provide the answer. In recent years, titanium had produced many surprises for scientists. And the first hint that this metal might be an unusual electron-tube material came from Beggs, supported by investigations of Dr. Paul Zemany and Dr. Francis Norton. Characteristically, the discovery and its exploitation drew upon the talents of several men. The first experiment to demonstrate its almost unbelievably efficient gettering properties was performed directly by Bondley, and the bulk of numerical data came from the subsequent detailed studies carried out by Dr. Virgil L. Stout and Martin D. Gibbons.

Now accurately measured and applied, this characteristic of titanium ranks in importance with such better known properties of the amazing metal as: strength of steel, weight approaching that of aluminum, and corrosion resistance of stainless steel. Other properties of titanium important in the development of miniature vacuum devices include excellent sealing characteristics, low vapor pressure, and high melting point.

Researchers at the Laboratory also degassed titanium at 800° C, well below the temperature required for any other metal tested. This property made titanium uniquely valuable for use in tubes employing oxide-coated cathodes. For uniform and consistent emission from oxide cathodes—a prime goal of tube research at General Electric for many years—requires freedom from poisoning contaminants. Thus a significant step toward success was achieved in discovering that titanium can be degassed at a temperature below oxide-cathode activation.

Mass spectrometer measurements showed that degassed titanium will absorb, or getter, a wide variety of gases—some even at room temperature. Equally important, titanium continues as an active getter throughout the life of the tube. Of all the gases gettered, only hydrogen is evolved on reheating to a high temperature. Thus use of both hot and cold titanium resulted in remarkable gettering. Employing titanium not only by using it as the principal structural material in the tubes but also by placing it on the walls of the high-temperature vacuum ovens that bake the tubes utilized these properties to the fullest.

New materials in the tiny tubes are ceramics specially designed to match the thermal expansion characteristics of titanium.

For Beggs and his associates became convinced that titanium held the answer to their desire for a tiny, rugged low-noise tube. But one problem remained: finding insulating disks to sandwich between slices of titanium. They needed ceramic bodies with expansion characteristics that matched those of titanium. Because none were commercially

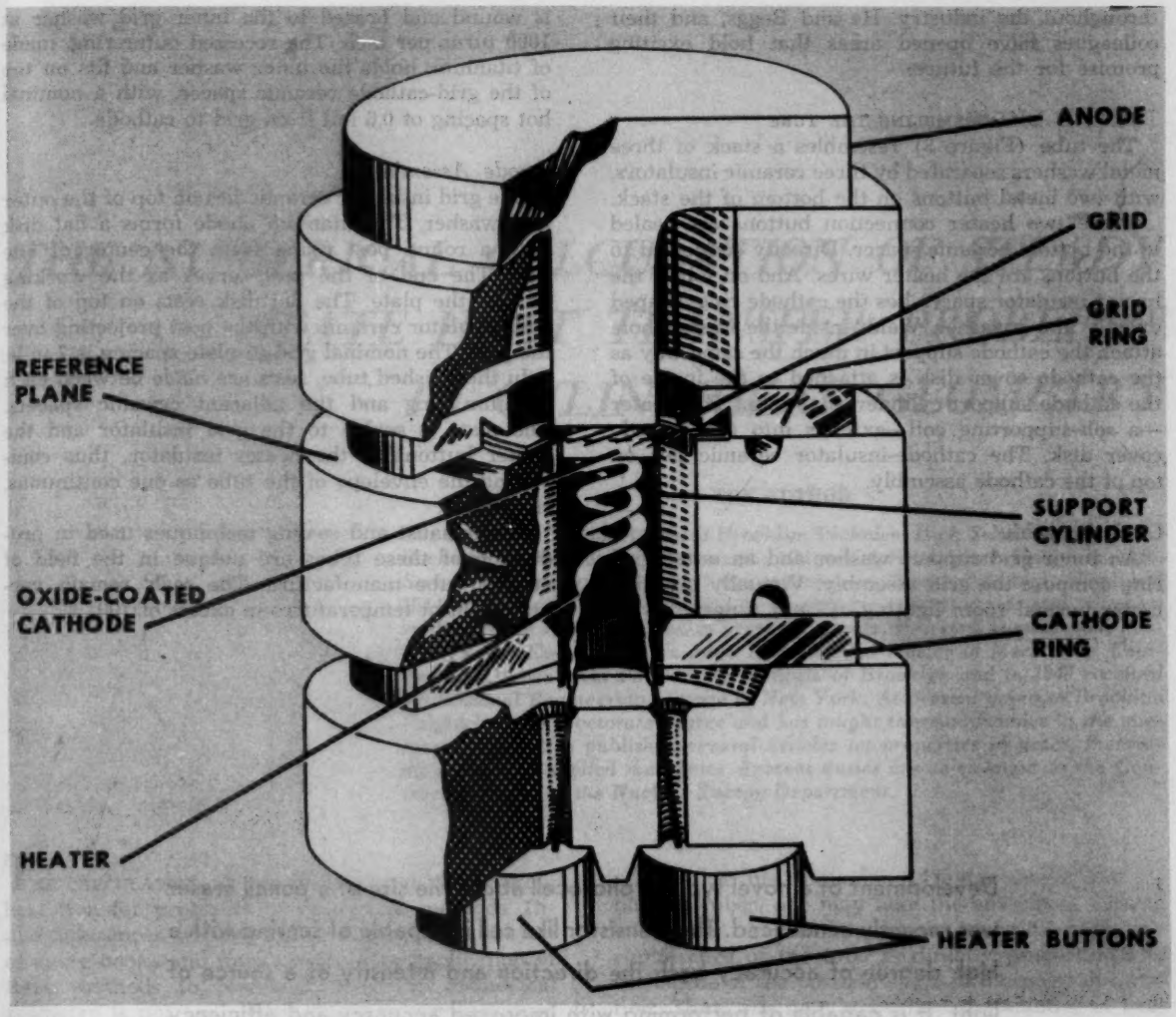

Figure 3. Structure. Size of a pencil eraser, the new tube offers high-gain low-noise ability to operate at temperatures above 500° C for electronic applications.

available, the Research Laboratory's ceramics section, largely through the efforts of Dr. Alexis G. Pincus and with the cooperation of Dr. Louis Navias, developed a series of bodies having thermal expansion and contraction characteristics almost identical to titanium.

New processes were necessary to make an entirely new type of grid and to produce metal-ceramic seals capable of maintaining a vacuum under strenuous operating conditions.

The electronic requirements of tubes for use at very high frequencies dictate that the geometry of the elements should be parallel planes. Grid structures, therefore, comprise a series of equally spaced wires soldered to a flat frame. During operation the grid wires become heated by direct radiation from the cathode and by electric energy dissipated in the grid itself. Dimensional changes that accompany heating of the wires may distort the geometry. To circumvent this difficulty, the scientists developed unique methods of winding the tiny grid wires, mounting them under tension, and nondestructive testing of the completed grids. The advent of smaller tube designs accentuated the problem. This necessitated refinements in further grid-making processes as an essential phase in developing miniature ceramic tubes.

Meanwhile, titanium-matching ceramics allowed soft solders to be discarded in the construction of small tubes. Research Laboratory scientists contributed a unique method of sealing metals and ceramics at temperatures near 1000° C. These seals also have added immeasurably to the ruggedness and consistent operating qualities of the new tubes.

McArthur's leadership in tube design—particularly his successful use of entirely new concepts, as in the lighthouse tube—is well recognized

throughout the industry. He and Beggs, and their colleagues have opened areas that hold exciting promise for the future.

ASSEMBLING THE TUBE

The tube (Figure 3) resembles a stack of three metal washers separated by three ceramic insulators, with two metal buttons on the bottom of the stack.

These two heater connection buttons are sealed to the bottom ceramic spacer. Directly connected to the buttons are the heater wires. And on top of the heater insulator spacer lies the cathode ring, shaped exactly like a washer. Welds inside the washer hole attach the cathode support in much the same way as the cathode cover disk is attached to the inside of the cathode support cylinder at the top. The heater —a self-supporting coil—extends into the cathode cover disk. The cathode-insulator ceramic lies on top of the cathode assembly.

Grid Assembly

An inner grid support washer and an outer grid ring compose the grid assembly. Virtually invisible under normal room lighting, 0.3 mil tungsten wire is wound and brazed to the inner grid washer at 1000 turns per inch. The recessed outer ring, made of titanium, holds the inner washer and fits on top of the grid-cathode ceramic spacer, with a nominal hot spacing of 0.6 mil from grid to cathode.

Anode Assembly

The grid insulator ceramic lies on top of the outer grid washer. The titanium anode forms a flat disk with a round post rising from the center of one side. The end of the post serves as the working area of the plate. The flat disk rests on top of the grid-insulator ceramic with the post projecting over the grid. The nominal grid-to-plate spacing is 7 mils.

In the finished tube, seals are made between each titanium ring and the adjacent ceramic spacers. The plate is sealed to the grid insulator and the heater buttons to the heater insulator, thus completing the envelope of the tube as one continuous, rigid piece.

The exhaust and sealing techniques used in production of these tubes are unique in the field of vacuum-tube manufacture. The seals remain vacuum tight at temperatures in excess of 700° C.

Development of a novel type of photocell about the size of a pencil eraser was recently announced. The transistor like cell is capable of sensing with a high degree of accuracy both the direction and intensity of a source of light. It is capable of performing with improved accuracy and efficiency many functions which have been handled previously only with as many as four separate conventional photocells. The device is based on the phenomenon that, when light is focused on a semiconductor junction, similar to those used in transistors, a small voltage is generated across the junction.

IRVING GRANET

THE NUMERICAL CALCULATION OF STEADY STATE HEAT TRANSFER PROBLEMS IN CYLINDRICAL GEOMETRY

THE AUTHOR

was born July 2, 1924. Attended Brooklyn Technical High School and received Bachelor of Mechanical Engineering Degree from Cooper Union in 1944. Served two years with Air Corps overseas as Flight Engineer. Employed 1944–45 on Navy Torpedo project as project engineer on stress and vibration studies. Since 1947, employed as project engineer, Research Department, Foster Wheeler Corporation. In June 1948 received Master of Mechanical Engineering Degree from Polytechnic Institute of Brooklyn and in 1949 received Professional Engineering License in New York. At present going to Brooklyn Polytechnic for Doctorate degree and has taught thermodynamics in the evening session. Has published several articles on properties of gases, thermodynamics and applied mechanics. Present duties are as assistant to the Contract Manager of the Nuclear Energy Department.

THE CALCULATION of two dimensional steady state heat transfer problems by numerical methods (finite differences, iteration, etc.), has been the subject of many books and monographs. The application of these methods to problems involving cylindrical geometry is not too readily found in the literature and in particular the boundary conditions for this geometry require careful consideration.

To illustrate both the method of calculation and the treatment of boundary conditions, a problem of practical interest has been chosen to which an analytical solution appears in the literature. This consists of a water-tube receiving plane radiation over the front half of its circumference. Such tubes are for all practical purposes those which are found in furnace waterwalls that are tangent. Figure 1 shows the essential geometry of the problem. It has been demonstrated that in such tubes the inside film coefficient is high enough to be regarded as essentially infinite and the inside surface may be considered to be isothermal and at the bulk mean temperature of the steam water-mixture in the tube (4). It will be further assumed that the heat being radiated to the tube does not vary along the length of the tube nor does it depend on the tube temperature. If necessary, these latter conditions can be accounted for by the method outlined herein.

Jakob, in his discussion (4), has shown that for tangent tubes, one may take the amount of radiant heat being received at any point along the outer circumference of the tube as directly proportional to the cosine of the position angle of the point in question. Thus, one may write that the amount of heat received by an element of surface is:

$$Q \cos\theta \, r_1 \, d\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Since the element of tube surface, $ds = r_1 d\theta$, the amount of heat received per unit tube surface is:

$$\frac{Q \cos\theta \, r_1 \, d\theta}{r_1 \, d\Theta} = Q \cos\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Thus, the boundary condition at the outer surface

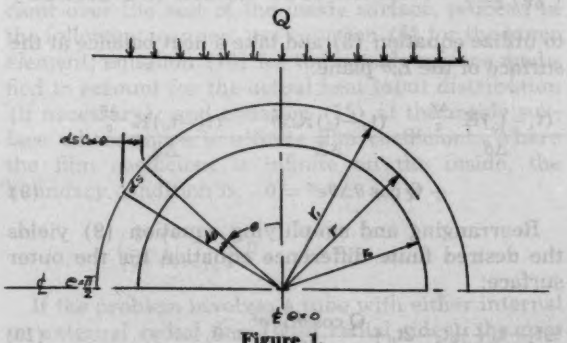

Figure 1.

of the tube from the Fourier heat conduction law is:

$$\left(\frac{\delta t}{\delta r}\right)_{r=r_1} = \frac{Q \cos\theta}{K} \quad \ldots\ldots (3)$$

For steady state heat conduction in two dimensions with no internal heat sources or sinks, Laplace's equation in cylindrical coordinates is (5):

$$\frac{\delta^2 t}{\delta r^2} + \frac{1}{r}\frac{\delta t}{\delta r} + \frac{1}{r^2}\frac{\delta^2 t}{\delta \theta^2} = 0 \quad \ldots\ldots (4)$$

In order to put this in a more convenient form for numerical calculations, the following transformation is made:

$$Z = \ln r; \frac{\delta Z}{\delta r} = \frac{1}{r}; r = e^Z \quad \ldots\ldots (5)$$

Equation (4) may now be transformed to the Z,θ plane by use of the formulae of the calculus (5) as follows:

$$\left.\begin{aligned} \frac{\delta t}{\delta r} &= \frac{\delta t}{\delta Z}\frac{\delta Z}{\delta r} = \frac{1}{r}\frac{\delta t}{\delta Z} = \frac{1}{e^Z}\frac{\delta t}{\delta Z} \\ \frac{\delta^2 t}{\delta r^2} &= \frac{\delta}{\delta Z}\left[\frac{1}{r}\frac{\delta t}{\delta Z}\right]\frac{\delta Z}{\delta r} = \frac{1}{e^{2Z}}\left[\frac{\delta^2 t}{\delta Z^2} - \frac{\delta t}{\delta Z}\right] \end{aligned}\right\} \quad \ldots\ldots (6)$$

Substitution of equations (6) and (5) into (4) yields:

$$\frac{1}{e^{2Z}}\left[\frac{\delta^2 t}{\delta Z^2} + \frac{\delta^2 t}{\delta \Theta^2}\right] = 0 \quad \ldots\ldots (7)$$

Since e^{2Z} is not in general zero, the expression in brackets must be zero. In the Z,θ plane, this corresponds to the Laplacian in rectangular coordinates. Emmons (3), Dusinberre (1) and others, have shown that for a numerical approximation (if equal spacings in both directions are used) this equation reduces to:

$$t_1 + t_2 + t_3 + t_4 - 4t_0 = 0 \quad \ldots\ldots (8) \text{ (with } \Delta\theta = \Delta Z)$$

where the temperatures are as shown in Figure 2.

Thus, for all interior points in the Z,θ plane, it becomes necessary to satisfy equation (8). For the inside boundary which was taken to be isothermal, $\left(\frac{\delta r}{\delta t}\right)_{r=r_0} = 0$. At the outer surface, it is necessary to utilize equation (3) and take a heat balance at the surface of the Z,θ plane.

$$\frac{(t_1 - t_0)K\frac{\Delta Z}{2}}{\Delta\theta} + \frac{(t_2 - t_0)K\Delta\theta}{\Delta Z} + \frac{(t_3 - t_0)K\frac{\Delta Z}{2}}{\Delta\theta} + Q\cos\theta\Delta\theta e^Z = 0 \quad \ldots\ldots (9)$$

Rearranging and simplifying equation (9) yields the desired finite difference equation for the outer surface:

$$\tfrac{1}{2}t_1 + t_2 + \tfrac{1}{2}t_3 - 2t_0 + \frac{Q\cos\theta\Delta\theta e^Z}{K} = 0 \quad \ldots\ldots (10)$$
(With $\Delta\theta = \Delta Z$)

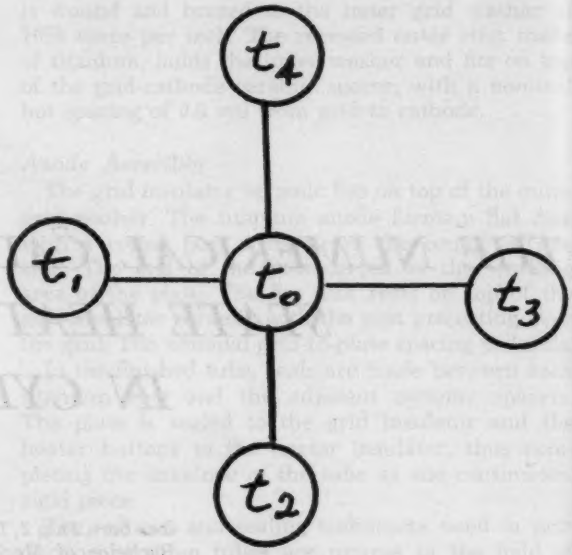

Figure 2.

Emmons has given an equation for the outer boundary which when reduced to the nomenclature of this paper is identical to equation (10) with the factor $\Delta\theta$ missing from the last term. This appears to be a typographical error in the Emmons paper.

In order to demonstrate the above analysis, the writer selected a tube having an outside diameter of 3″ and an inside diameter of 2″. Thus,

$$\frac{e^Z \Delta\theta\, Q\cos\theta}{K} = \frac{1.5\,\Delta\theta\, Q\cos\theta}{12\,K} \quad \ldots\ldots (11)$$

To demonstrate the method and also indicate that a coarse network gives reasonable engineering results, the writer selected three radial divisions. Therefore, $\Delta\theta$ equals $\frac{\ln 1.5 - \ln 1}{3} = 0.135$ and $\Delta\theta = 0.135 \times \frac{180}{\pi} = 7.72°$. Thus, equation (11) becomes

$$(\text{with } \Delta\theta \text{ in radians} = 0.135) = \frac{.0169\,Q\cos\theta}{K} \quad \ldots\ldots (12).$$

Since both Jakob and Dusinberre have calculated this problem analytically based on a temperature drop of 100°F, at $\theta = 0$, the writer has chosen this as the base point for the calculation. The heat flow at $\theta = 0$ is radial due to symmetry. Thus, $\frac{Q}{K} = \frac{100}{(r_1 - r_0)}$, which for this case equals 2400. Inserting this into (12) gives the following:

$$\frac{e^Z\,\Delta\theta\, Q\cos\theta}{K} = 0.0169 \times 2400\cos\theta = 40.6\cos\theta \quad \ldots\ldots (13)$$

It is noted that $\frac{180}{7.72} = 23.3$ so that the number of $\Delta\theta$'s

must equal 23.3 and up to $\theta = \frac{\pi}{2}$, there are 11.65 $\Delta\theta$'s. For simplicity of calculation, it will be taken that there are 12 $\Delta\theta$'s to $\frac{\pi}{2}$ and 23 $\Delta\theta$'s to π. The error incurred by this approximation will be small. Table 1 gives the required values of equation (13) for various θ's.

The problem is begun by laying out the rectangular grid and assuming temperatures at each grid point in the Z,θ plane. One then calculates by the difference equations (8) and (10) the residues (the amount that the assumed temperatures placed into equations (8) and (10) deviate from the zero equality). The temperature of each lattice point is systematically corrected in an attempt to reduce the residues to zero. Since a relatively coarse network was chosen, the author "relaxed" the residues at each point until the error was of the order of magnitude of 1° F. These results are transformed back to the r,θ plane by noting that $r = e^z$. From the calculations, the desired temperature pattern is established by interpolation. The process is a rapidly convergent one and any degree of accuracy can be obtained by going to finer and finer networks. The results of the coarse network were plotted and various isotherms established by interpolation. Figure 3 shows the results which for most engineering purposes are identical to the Dusinberre and Jakob results.

If there is a finite film coefficient on the interior, $\left(\frac{\delta t}{\delta r}\right)_{r=r_0} \neq 0$, it is necessary to obtain a boundary condition in the Z,θ plane for this case. Proceeding as before and writing a heat balance and for t_2 in Figure 2 using t_f, the bulk fluid temperature, equation (14) is obtained:

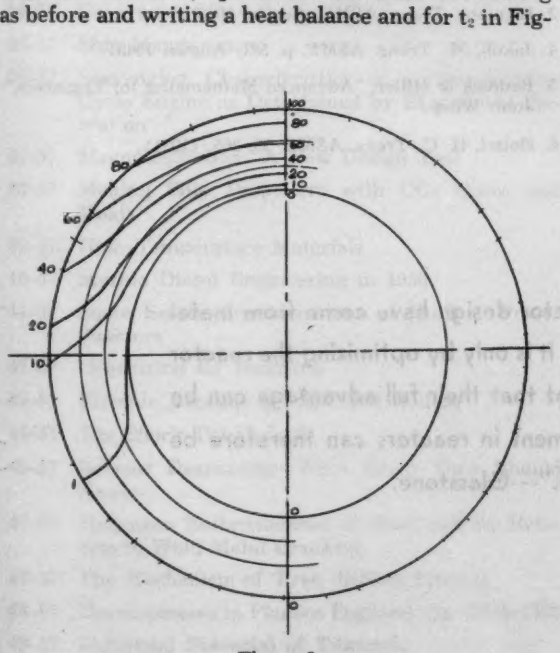

Figure 3.

Table 1

θ-degrees	Cos θ	40.6 Cos θ
0	1	40.6
7.72	0.990	40.1
15.44	0.965	39.2
23.16	0.920	37.3
30.88	0.860	34.9
38.60	0.780	31.6
43.32	0.730	29.6
54.04	0.586	23.8
61.76	0.474	19.2
69.48	0.350	14.2
77.20	0.222	9.0
84.92	0.134	5.4
92.64 (90)	0	0

$$\frac{(t_1-t_0)}{\Delta\theta}\frac{K\Delta Z}{2} + \frac{(t_3-t_0)}{\Delta\theta}\frac{K\Delta Z}{2} + \frac{(t_4-t_0)K\Delta\theta}{\Delta Z} + h\,e^z\,\Delta\theta\,(t_f-t_0) = 0 \quad \ldots\ldots\ldots\ldots\ldots (14)$$

Reducing and rearranging equation (14) yields the desired finite difference equation for the inner surface when $\Delta\theta = \Delta Z$:

$$\frac{t_1}{2} + t_4 + \frac{t_3}{2} + \frac{h\,e^z\,\Delta\theta}{K} t_f - \left[2 + \frac{h\,e^z\,\Delta\theta}{K}\right] t_0 = 0 \ldots\ldots (15)$$

Thus, only equations (8), (10) and (15) are needed for this problem. It is apparent that these three equations can be modified to take care of any distribution of heat input, radial or otherwise. Actually, one need only modify equation (10) to account for any variation in heat input. For the case of plane radiation to non-tangent tubes backed by refractory, the preferred procedure is that recommended by Hottel (6). If the tube has an insert, so that effectively there is a finite film coefficient over part of the inside surface and an infinite film coefficient over the rest of the inside surface, proceed in the following manner: use equation (8) for the inner element; equation (10) for the outside surface modified to account for the actual heat input distribution (if necessary); and equation (15) at the inside surface where there is a finite film coefficient. Where the film coefficient is infinite on the inside, the boundary condition is:

$$\left(\frac{\delta t}{\delta r}\right)_{r=r_0} = 0$$

If the problem involves a tube with either internal or external radial fins (with radial sides) the procedure is identical to that previously outlined, since

the fins will transform to rectangles in the Z,θ plane. If the fin is not radial or has non-radial sides, several approaches may be used. The fin may be transformed to the Z,θ plane and the resulting shape approximated by small finite squares. An alternate, more general approach, is to retain both the rectangular geometry of the fin and the transformed rectangular geometry of the tube. If the spacing of the rectangular grid is made to correspond to the value of ΔZ (the first space $= r_1(e^z - 1)$ and all subsequent spaces in rectangular geometry equal to this value), one may write a simple coupling relation at the base of the fin. The degree of accuracy of this approach increases with decreasing fin thickness. It is also possible to use triangular grids to obtain the necessary coupling relation.

The problem worked out took the writer slightly less than two hours to solve. With a desk calculator, this problem could be solved in less than one hour. In doing the problem, each point was successively calculated. By using a grouping of points ("block relaxation"), the time and labor of obtaining the solution could have been greatly decreased. It is apparent that many such problems covering a wide range of parameters can be solved in a relatively short time. The most difficult and time consuming part of any problem when solved numerically is establishing the proper boundary conditions.

$\frac{\delta}{\delta r}$ = Partial derivative with respect to r

$\frac{\delta}{\delta \theta}$ = Partial derivative with respect to θ

$\frac{\delta^2}{\delta r^2}$ = Second partial derivative with respect to r.

$\frac{\delta^2}{\delta \theta^2}$ = Second partial derivative with respect to θ.

$Z = \ln r$ = Natural logarithm of r

$\frac{\delta}{\delta Z}$ = Partial derivative with respect to Z

$\frac{\delta^2}{\delta Z^2}$ = Second partial derivative with respect to Z

$$\Delta Z = \Delta \ln r = \frac{\ln r_1 - \ln r_2}{\text{No. of Divisions}} = \Delta \ln r$$

NOMENCLATURE

Q = Rate of heat input per square foot of projected area $\frac{\text{BTU}}{\text{Hr Ft}^2}$

θ = Angular position radians

r_1 = Outer tube radius—(inches or ft.)

r_0 = Inner tube radius—(inches or ft.)

r = Any tube radius—(inches or ft.)

$d\theta$ = Differential angle

ds = Element of surface $= r\,d\theta$ = sq. ft. per unit length

K = Thermal conductivity $- \frac{\text{BTU}}{\text{Hr ft}^2\,^\circ\text{F}}$ (where ft^2 units correspond to units for r)

$\Delta\theta$ = Small increment of angle—radians

t_0, t_1, t_2, t_3, t_4 = Temperatures °F corresponding to grid points in Figure 2.

t_f = Bulk fluid temperature of coolant °F.

h = Film coefficient at inner surface $- \frac{\text{BTU}}{\text{Hr. Ft}^2\,^\circ\text{F}}$

e = 2.718

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"In general, the major advances in reactor design have come from materials and fabrication developments, but it is only by optimizing the reactor systems from a heat-transfer standpoint that their full advantage can be realized. A large part of the improvement in reactors can therefore be attributed to good heat-transfer design."—Glasstone.

JOHN W. SAWYER

ENGINEERING ABSTRACTS

Number	*Abstract Title*
26–57	Combining Hydraulic Torque Converters with A-C Motors
27–57	Fires in Ships
28–57	Application of the Electronic Probe to the Study of Turbulent Flames
29–57	Tooth Gearing and Research
30–57	Recent Uses of Radioactive Isotopes in Britain
31–57	Phenolic Coatings for Metal Products
32–57	The Solution of Engineering Problems by an Electric Analogue Computer
33–57	Steam and Gas Turbines
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35–57	Ship Maintenance
36–57	Scavenging Characteristics of a Two-Stroke-Cycle Engine as Determined by Skip-Cycle Operation
37–57	Magnetostriction: A New Design Tool
38–57	Making Ship Propellers with CO_2 Cores and Molds
39–57	High-Temperature Materials
40–57	Marine Diesel Engineering in 1956
41–57	Some Safety Considerations of Nuclear Power Reactors
42–57	Organizing for Research
43–57	Fireside Deposits in Oil-Fired Boilers
44–57	The Shock Tube
45–57	Solvent Degreasing—What Every User Should Know
46–57	Hydrogen Embrittlement of Steel and its Relation to Weld Metal Cracking
47–57	The Mechanism of 'Free' Rolling Friction
48–57	Developments in Plastics Engineering—1955-1956
49–57	Industrial Potential of Titanium

Number *Abstract*

26–57 "Combining Hydraulic Torque Converters with A-C Motors"—Wayne Howard; Electrical Manufacturing, V. 59, n. 2, Feb. 1957, pp. 90–93, 330. Hydraulic torque converters coupled with a.c. motors enable designers to select speed-torque characteristics to suit high inertia loads. The hydraulic torque converter eliminates the need for disconnect clutches and also simplifies the starting systems. It serves an additional role as an overload protection. For constant load or constant speed applications, the torque converter should not be used. Where heavy starting and wide variations in load demands are encountered the hydraulic torque converter can be used to advantage. Discussion includes torque converter principles, performance, applications and motor-converter combinations.

27–57 "Fires in Ships"—The Institute of Marine Engineers Transactions, V. LXVIII, n. 12, Dec. 1956, pp. 471–537. A number of papers were presented before the Institute of Marine Engineers and the Institution of Naval Architects on fires in ships. These papers include the following:

1. "Survey of the Causes and Methods of Extinction of Fires in Ships"—F. J. Welch. Material covers: cargo and cargo space fires, detection and extinction of these fires, machinery space fires and their extinction, closing of openings, breathing apparatus, avoidance of capsizing in fighting major fires.
2. "Principles of Fire Organization in Ships at Sea and in Port"—A. G. Bates. Subjects include: fire risk and material, prevention, warning and action, and planning.
3. "Naval Procedures in Relation to Fire Organization"—L. T. Carter and H. C. Hogger. Fire

Number *Abstract*

fighting in the Royal Navy, fire prevention, protection, pumps, foam, spray systems, machinery spaces, avgas stowage, flight deck, hangars, portable pumps (including gas turbine and diesel), ship organization and personal equipment are discussed. (This paper is reprinted in this issue of the JOURNAL.)

4. "Research in Relation to Ship Fires"—S. H. Clarke and S. A. Hodges. The research and tests that have gone into the study of ship fires are summarized.

28–57 "Application of the Electronic Probe to the study of Turbulent Flames"—D. W. Denniston, J. R. Oxendine, D. H. Knapschaefer, D. S. Burgess and B. Karlovitz; Journal of Applied Physics, Jan. 1957, V. 28, n. 1, pp. 70–75. In studies of structure, propagation and stability of turbulent flames the electronic probe has proved useful. The probe, operation, application and limitations are presented.

29–57 "Tooth Gearing and Research"—S. A. Couling, The Engineer, V. 202, n. 5266, Dec. 28, 1956, pp. 915–918. This paper was presented before the British Gear Manufacturers' Association in London on November 13, 1956. Material presented includes the following as related to tooth gearing: history, fundamental research, applied research, design, production, lubrication, metrology, general problems, hob form and effects on profile, loading formulae and curves of profile errors.

30–57 "Recent Uses of Radioactive Isotopes in Britain"—John F. Carneron; Metal Progress, V. 71, n. 1, Jan. 1957, pp. 103–108. Economic geological mapping can be done with use of radioactive isotopes. Ventilation studies on dispersion of gas and dust have been made by employing radioactive tracer methods. True mean air flows may be measured by determining the mean speed of travel of a pulse of tracer or the dilution of a continuously released tracer. Process control of plate thickness is achieved by this technique. Many research applications are being developed. Tests are being conducted on tool life, wear rates and lubricant efficiencies.

31–57 "Phenolic Coatings for Metal Products"—R. B. Young; Materials & Methods, V. 45, n. 1, Jan. 1957, pp. 106–109. Phenolic coatings have excellent resistance to chemical attack, solvents, oil and water. They also have good resistance to abrasion and wear. Many metal surfaces are coated with phenolic resins. Applications include tank linings and primers. Principal types are: straight phenolics, polyhydroxy phenolics, blocked phenolics and phenolic oil varnishes. Coatings may be applied by spray, dip, roller, flow and slush coating.

32–57 "The Solution of Engineering Problems by an Electric Analogue Computer"—J. G. Miles; The Metropolitan-Vickers Gazette, V. XXVII, n. 449, Dec. 1956, pp. 368–376. The solution of problems in design and application in electrical engineering by use of the electronic differential analyzer is illustrated. The principle of operation is described. The computer is currently used for: obtaining transient responses of electrical networks; assisting in observation of effect of variation in control system parameters; solving differential equations that describe performance of nuclear reactors and other apparatus. Case problems and their solutions are shown on: switching overvoltages on long lines; rolling mill voltage control; switching of unloaded transformers.

33–57 "Steam and Gas Turbines"—Hans Steiner; Swiss Technics, n. 3, 1956, pp. 41–52. Development of steam and gas turbines for power generation in Switzerland is outlined. Progressive metallurgy, better steel production, generator construction and use of higher pressures have combined to increase over-all steam plant efficiencies to more than 40 per cent. Gas turbines are increasing in applications in electric power stations, manufacturing and steel works. Units have capacities up to 30,000 k.w. Turbo-superchargers are now being used for large two-stroke diesels. A number of applications of steam and gas turbines and turbo-superchargers are described.

34–57 "Government Specifications"—M. Barov: Machine Design, V. 29, n. 3, Feb. 7, 1957, pp. 76–80. It is important for designers who are concerned with equipment for Government use to have a knowledge of Government specifications and standards. Specifications are needed by the Government to: assure proper quality; simplify storage and stock control; secure sources of reliable replacements. Deviations from Government specifications are necessary at times. Specifications are prepared jointly by the Army, Navy and Air Force under cognizance of the Department of Defense, Standardization Division. One service may prepare certain specifications limited to its own use. Federal specifications usually apply to non-military as well as military items. An index of specifications, related publications, agencies issuing specifications, and standards are included.

35–57 "Ship Maintenance"—International Design & Equipment, A Shipbuilding & Shipping Record Publication, 1957, pp. 33–43. A series of articles on methods of more efficient ship design, which outline means to reduce maintenance and repair costs. These include:

1. "Design of Ships for Easier Maintenance"—David Skae.
2. "The Layout of Machinery for Easier Maintenance"—H. T. Meadows. Diesel machinery, bearing shells, generators, pumps, heat exchangers, tail shaft, turbine machinery, and boiler room are discussed.

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3. "Plastics in Ships for Easier Maintenance"—John West.

4. "Combating Corrosion"—John West.

5. "Maintenance of Double-Plate Rudders"—R. F. Serbutt.

6. "The Contribution of Aluminum"—E. G. West.

36–57 "Scavenging Characteristics of a Two-Stroke Cycle Engine as Determined by Skip-Cycle Operation"—P. M. Ku and T. F. Trimble; Journal of Research of the National Bureau of Standards, V. 57, n. 6, Dec. 1956, pp. 325–331. A simple method is presented for determining the mass fraction of fresh charge in the engine cylinder after port closure. Tests were conducted on a crankcase-scavenged engine. The experimental test equipment and instrumentation are described. It was found that the mass fraction of fresh charge in the cylinder was a function of scavenging ratio only. This was true regardless of the values of engine speed, inlet pressure or exhaust pressure within the limits investigated. Tests show this method to be practical and reliable.

37–57 "Magnetostriction: A New Design Tool"—Edward M. Wise; Product Engineering, V. XXVIII, n. 1, Jan. 1957, pp. 162–166. Magnetostriction, the change in size of some ferromagnetic materials when placed in a magnetic field, provides a means of converting electrical to mechanical energy. Large static forces or small displacements can be generated from zero to ultrasonic frequencies. The magnetostriction transducer can: drive high impedance loads; operate efficiently under high temperatures, moisture and hydrostatic pressure; be adapted to a wide range of sizes and power ratings; operate in a frequency range 5 to 100 k.c. Applications include: cleaning and degreasing, welding of similar or dissimilar metals, soldering, machine tool feed and fuel injection system.

38–57 "Making Ship Propellers with CO_2 Cores and Molds"—Robert H. Herman; Foundry, V. 85, n. 2, Feb. 1957, pp. 104–109. Methods used by a foundry in producing bronze alloy propellers are outlined. Cores and molds are sodium silicate-bonded, hardened with CO_2. Propellers up to 13,000 pounds have been cast in the CO_2-hardened molds. Principal advantages of the CO_2 method are: elimination of excess metal by swells, fidelity of castings to pattern dimensions and reduction of grinding time to bring swelled castings down to size.

39–57 "High-Temperature Materials"—H. E. Gresham; Engineering, V. 182, n. 4738, Dec. 28, 1956, pp. 818–820. Metals and alloys for aircraft engines are reviewed. Alloys include: Stayblade, Rex. 78, Inconel, Staybrite and aluminum alloy RR59. Materials for nozzle guide vanes, turbine discs and gas turbine blades and their development over the past fifteen years are presented.

40–57 "Marine Diesel Engineering in 1956"—The British Motor Ship, V. XXVII, n. 440, Jan. 1957, 414–419. In 1956 two more classes of slow-speed, two-stroke diesels completed satisfactory trials with turbo-chargers. A number of 15,000 b.h.p. turbo-charged, single acting, two-stroke engines are on order. Every type of slow-speed marine two-stroke engine is now available with turbocharging. High speed engines for geared and electric propulsion are under consideration. Several orders have been placed for vessels with free piston propulsion plants.

41–57 "Some Safety Considerations of Nuclear Power Reactors"—C. D. Boadle; North East Coast Institution of Engineers and Shipbuilders Transactions, V. 73, Part 2, Dec. 1956, pp. 63–85. Generation of large quantities of electric power with nuclear reactors raises new hazards not encountered with more conventional systems. Prevention of the release, in an uncontrollable manner, of large amounts of radioactive fission products is mandatory. Accidents that result in core structure damage require unusual repair measures which can be extremely time-consuming, costly and a hazard to personnel. Reactor mishaps can be placed in three groups, according to causes: incidents arising from an uncontrolled power excursion; incidents due to a failure of the cooling system; incidents where the reactor container or primary cooling circuit is ruptured. Causes and effects of these mishaps are discussed. Protective equipment for reactors, reactor designs and characteristics of advanced systems are presented. References, graphs, illustrations.

42–57 "Organizing for Research"—E. I. Brimelow; Metallurgia, V. 54, n. 326, Dec. 1956, pp. 276–282. A series of papers and discussions were presented recently at the National Physical Laboratory on problems relating to research in Government and industry. Today research is so costly that substantial grants are required for university support. About 325M pounds or 2 per cent of Britain's gross national product was spent on research and development in 1955–56. In the United States 10–12 per cent a year is spent on research and development. Optimum size of organization depends on many factors. Close integration of work within an organization is likely to produce more bright ideas. Selection of research projects, assessment of research, conditions for creative work, incentives and rewards, laboratory administration, budgets and administrative control, and communications were subjects considered.

43–57 "Fireside Deposits in Oil-Fired Boilers"—Clarence Jacklin, Donald R. Anderson and Harris Thompson; Industrial and Engineering Chemis-

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try, V. 48, n. 10, Oct. 1956, pp. 1931–1934. Slag and corrosion problems in boilers burning residual fuels have increased during recent years. This increase is partially due to the greater ash content in residual fuel now being produced. Refining processes have increased the yield of high value products and as a result decreased the amount of residual produced per barrel of crude. Methods for prevention and control of fireside deposits include both the mechanical and chemical approach. The pattern of composition and method of formation of deposits in an average residual oil-fired boiler are developed. Deposit formation mechanisms are: precipitation from vapor by condensation or desublimation or both; adhering of molten or semi-molten particles; entrapment of solids on molten or sticky surfaces. Methods of depositing different elements on boiler surfaces are tabulated. Sodium, vanadium, nickel and sulfur seem to condense or desublimate from vapor in one or more boiler sections. Sodium and vanadium compounds, in molten form, adhere to high temperature tubes or deposits by splashing. Silicon, magnesium and calcium are kept in deposits by entrapment.

44–57 "The Shock Tube"—F. S. Sherman; Research Reviews, Jan. 1957, pp. 1–9. The shock tube is widely used in a variety of research fields including aerodynamics, heat transfer, thermodynamics and physical chemistry. It was given a start in the United States by the Office of Scientific Research and Development and later sponsored by The Office of Naval Research. Shock tubes fall into four general classes: piston, diaphragm, solid explosive and electric. Research uses include: investigation of properties and behavior of shock waves; investigation of properties of the driven or shock-processed gas; aerodynamic model testing in the driven gas.

45–57 "Solvent Degreasing—What Every User Should Know"—C. E. Kircher; ASTM Bulletin, n. 219, Jan. 1957, pp. 44–49. Cleaning by solvent degreasing is widely used by the metal-working industries. Some 20,000 solvent degreasing units are now in use in the U. S. The annual sale of trichloroethylene for metal cleaning is estimated at 250,000,000 lb. The production, testing and stabilization of this solvent is presented in order to give users information for evaluating results and test procedures.

46–57 "Hydrogen Embrittlement of Steel and its Relation to Weld Metal Cracking"—H. G. Vaughan and M. E. de Morton; British Welding Journal, V. 4, n. 1, Jan. 1957, pp. 40–61. Material includes: existing theories of hydrogen embrittlement; nature of embrittlement; results of tensile tests of as-received steels and hydrogen-charged steels; examination of cracking in weld metal; effect of cathodic charging with hydrogen; effect of hydrogen on weld metal ductility; relation of hydrogen embrittlement to weld metal cracking.

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47–57 "The Mechanism of 'Free' Rolling Friction"—D. Tabor; Lubrication Engineering, V. 12, n. 6, Nov.-Dec. 1956, pp. 379–386. A study of the mechanism of rolling friction in the elastic range is described. It is considered that the elastic hysteresis losses in the solids is the major source of free rolling friction. The paper covers: rolling in the plastic range, rolling of cylinders in the elastic range, rolling of spheres on flat rubber, differential slip in rolling, rolling of a sphere in a metal groove, and surface interaction. Rolling resistance is due primarily to deformation losses in the solids in free rolling. Boundary lubricants result in no detectable diminution in rolling resistance because interfacial effects are small.

48–57 "Developments in Plastics Engineering—1955-1956"—Bryce Maxwell; Mechanical Engineering, V. 79, n. 2, Feb. 1957, pp. 161–164. Great strides have been made both in developing new plastics and new products during 1956. The current production rate is 3.4 billion pounds per year as compared to 2.7 billion pounds last year. It is indicated that 8.5 billion pounds may be produced in 1960. Some 65 major expansions have been made in the production facilities of plastic producing companies in the past six months. Materials development include: new polymers, improvement of older plastics by new polymerization techniques, new curing agents, modified epoxies with pot lives up to eight days and others. Fabricating processes include: the perforated "polyliner" that increases injection molding capacity; adiabatic extrusion; new extrusion machines and improved vacuum forming techniques. Engineering developments have increased our ability to design and fabricate better plastic items. The effects of atomic radiation on polymers is under continued study. New applications include: automotive, jet fuel tanks, pressure vessels and house construction.

49–57 "Industrial Potential of Titanium"—Ronald L. Carmichael; Battelle Technical Review, V. 5, n. 12, Dec. 1956, pp. 9–13. Titanium has many outstanding properties that make it suitable for some exacting requirements of both military and industry. It shows useful strength up to 1000° F. The U. S. Government uses about 95 per cent of titanium in this country. Industrial applications are increasing. Advantages include: corrosion resistance; high strength-weight ratio; good abrasion resistance. Disadvantages include: high cost; difficulty in welding; ease of galling; scrap loss due to inexperience of fabricators. Present uses are illustrated as follows: Aircraft such as the DC-7 will require about 800 pounds, raw-weight, in the engine cowling and fire wall; chemical industry for pump impellers; filter press parts; marine industry for heat exchangers, snorkel tubes, piping systems, globe valves; electrical industry for micro-miniature tube parts.

BOOK REVIEWS AND NOTICES

THE RADIO AMATEUR'S HANDBOOK

34th Edition — 1957

Published by American Radio Relay League, Inc.

West Hartford, Connecticut

760 pages

Price: In the United States $3.50

In U.S. Possessions and Canada $4.00

Elsewhere $4.50

This edition takes note of the changes in technical practices that have occurred in recent years. An appreciable amount of new equipment in all categories appears throughout the book. The chapter on receiver construction describes both simple and complex designs for complete receivers and various add-on-units. The transmitter section features units for the novice as well as for the more experienced amateur. Additions to the v.h.f. sections include high-powered amplifiers and beam antennas.

The basic theory sections include a chapter on semiconductors, in keeping with their growing importance to the art. The always-informative data chapter on vacuum tubes has been completely rewritten and re-arranged for maximum legibility and convenience.

As it has for a number of years, the Handbook also contains a large catalog section, featuring communications equipment of the nation's leading manufacturers. In most cases, complete specifications and measurements are given to assist the constructor.

The Handbook is profusely illustrated, containing over 1350 illustrations, including 502 tube-base diagrams.

ROLL-ON, ROLL-OFF SEA TRANSPORTATION

Proceedings of a Symposium

convened by

The Maritime Cargo Transportation Conference of the National Academy of Sciences—National Research Council

Published in 1957

by National Academy of Sciences—National Research Council, 2101 Constitution Avenue, Washington 25, D.C.

52 pages — $1.25

The Maritime Cargo Transportation Conference (MCTC) has been conducting a series of studies on the sea transportation of dry cargo, one of which includes roll-on roll-off sea transportation. A symposium was convened on November 19, 1956 in connection with this study, and this pamphlet is the proceedings of that conference. One hundred thirty-eight representatives of Government, the Academy-Research Council, and all phases of the maritime industry attended.

Seven papers were presented at the symposium by members of the staff of the National Academy of

Sciences - National Research Council, trailership operators, a naval architect, the Maritime Administration, and the Department of Defense. There was a discussion of the principles which influence the roll-on, roll-off operations in which it was stated that the principles of "Unit Size" and "Mechanical-Equipment" are vital for the trailership. The length of voyage affects the contest between the "Terminal-Time" and "Lost-Space" principles. The importance of ship construction and operation costs is overwhelming in roll-on, roll-off sea transportation, especially for longer voyages. The discussion emphasized the afore-mentioned principles and others such as "Loss and Damage," "Flexibility," "Terminal Through-Put" and "Safety."

The operation of a hypothetical new Clipper ship was compared with the operation of a hypothetical new trailership of the same speed. The Maritime Administration outlined trailership port requirements, and a naval architect discussed some principles of roll-on, roll-off ship construction. The development of a current trailership industry and the development of trailerships of tomorrow were discussed by the president of a trailership company. The Department of Defense explained its interest and need for trailership operations in peace and war.

The pamphlet of the proceedings contains the seven papers which were presented and an edited version of the questions, answers, and discussion which followed each presentation.

SHIP AND BOAT BUILDER ANNUAL REVIEW

1957

compiled by

"Ship and Boat Builder"

Published in London in 1957

John Trundell, Limited

384 pages. Price in London: 40 Shillings

With a foreword by Denys H. Sessions, President-Elect, Ship and Boat Builders' National Federation

This book contains 13 articles on such subjects as "European Shipbuilding Survey," "Techniques in Steel Shipbuilding," "Developments in Plastic Construction," "Air Cooling for Marine Engines," and "An Appraisal of Soviet Naval Strength."

The main body of the book is devoted to a directory of Boat Builders in Great Britain and Overseas, a section on specifications of marine engines, one on "Materials, Fittings and Equipment" and additional directories of Consultants (Great Britain); Associations (Trade, Learned Societies and Miscellaneous); British owners of small craft; Dock and Harbor Authorities of Great Britain and Ireland; Commercial Diplomatic Officers and Trade Commissioners; and British Yacht Clubs.

CHANGES IN MEMBERSHIP

ADDITIONS TO MEMBERSHIP

The Society is very much pleased to state that the following have become members since the publication of the February, 1957, JOURNAL.

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The Society is grieved to be forced to report the loss by death of the following:

Anderson, Charles Harper, Naval Member

Meurk, B. E., Associate Member

Rice, Winthrop Merton, Civil Member

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LIEUTENANT GENERAL LEWIS B. HERSHEY, U. S. Army

SPECIALIZED MANPOWER

As the JOURNAL *went to press we did not have a copy of General Hershey's talk at the annual banquet. We had made no provision for recording the talk and the speaker did not have a prepared speech. In the Secretary's Notes, the editorial staff included certain highlights which it had gleaned, subjectively, from the speaker's words.*

This talk made such a deep impression and was so favorably commented on, that the President of the Society importuned General Hershey to try to duplicate it for the record.

This, the General most graciously agreed to do and has done. Naturally, these are not the same words which he spoke at the banquet. The apparent discrepancy between the "highlights" and the following draft are, at least in part, due to the use of different phraseology to express the same general idea. Even so we hasten to relieve General Hershey from any responsibility for the composition of the highlights and at the same time offer to our readers General Hershey's own words, indited ex post facto.

Dinner of The American Society of Naval Engineers,
Statler Hotel, May 3, 1957

Mr. Toastmaster, Mr. President, Past Presidents, Bureau Chiefs, Engineers, real and alleged, and representatives of great corporations who steal engineers from each other.

I am flattered and frightened to be present at this great gathering of engineers. I am flattered that I am permitted to speak to such an unusual group in such impressive numbers. I am frightened for exactly the same reason. I know there is a great shortage of engineers in this country. I know the measures for our defense that are said to lag even now because of a dearth of engineers. Yet, knowing the facts, I must face the awareness that in fifteen minutes I shall remove from productive technical endeavour hours, yes days, weeks, even approximately two months of engineer manpower. It gives me pause to contemplate what it may mean to national security to not only under utilize two months of engineer brainpower, but to all intents and purposes neutralize it completely.

I can offer few reasons why I am competent to speak to engineers normally permitted to consider themselves experts. Presenting a week case for this presumption I did attend a college of education and liberal arts which had a College of Engineering on the same campus. Some association was inevitable as the trigonometry, the analytical geometry, the mechanics, and higher physics that were inflicted in those days on liberal arts students in the college I attended was taken in the College of Engineering. I hasten to assure you I have no desire to have you lose faith in my truthfulness by understanding that I infer that I was a student in the subjects I have just named. I only want to assert that I was enrolled in the classes at the same time that men who later became engineers were. The fact that I received credit could be accredited to sympathy, or merely to selfishness of the professor who could not face the prospect of taking me into the vicinity of the subject matter the second time.

It was my privilege to be associated against engineers in intra-mural basketball and integrated, if that is not a bad word, in varsity basketball.

Later I spent four years as an Assistant Professor of Military Science and Tactics at The Ohio State University. At that time I was at least attached, for pay purposes, to the Artillery. While there the great majority of the Artillery ROTC students were enrolled in the College of Engineering. Let me make it clear, they were being exposed to artillery with horses by me not to engineering. It was believed by some that the technique of artillery came more easily to the prospective engineer.

You are more capable of judging than I am as to whether the experiences I have related prepared me

for the task of providing for deferment for engineers during World War II and the Korean conflict. Prepared or not, I was there. How many men, now engineers, were helped in any way to be so by deferment or under the GI Bill I am unable to say. Selfishly one would hasten to claim credit on a large scale, not forgetting perhaps that there is a responsibility some one must bear for the ones deferred who failed to become engineers or worse yet, became engineers who were liabilities rather than assets to society.

As a final item in this plea, I am at present a trustee of Tri-State College, Angola, Indiana, which is engaged in graduating engineers four times a year. I might note that companies recognize Tri-State by hiring its students but in distributing grants find that we are not properly accredited to participate in receiving what I presume were profits which Tri-State engineers apparently aided the companies to earn.

In a discussion of specialized manpower an early obstacle is identification. What is specialized and what is not? In fact, there is no little confusion as to what constitutes manpower. We talk much of how many men we have and as yet we are far from agreement what a man is as a unit of measure.

The engineers can, perhaps, be identified more easily than some professions but he has not gained the position occupied by the physician and the dentist. These two professions have been able to stifle competition to a large degree by securing the enactment of laws jailing competitors who do not belong. It has been my observation that the members of any profession are respected by the degree the public is mystified by the functions they presumably perform. For example, the ministers are held in high esteem because they are supposed to know much about the nature of the great unknown of life. Physicians have a high standing because they are presumed to know with some accuracy the time that human being may be changing their status from life to the unknown. Chemists unite harmless looking material to make noise, cause fire, or generate smells, to the mystification of the unknowing. You engineers, by blue prints and formula, leave an impression of knowledge that impresses us regardless of its real validity.

So we have come to hold the engineer in awe and we in Selective Service have seen the efforts made to borrow a little of the radiance of this profession. We have known of self-classified maintenance engineers who turned out to be janitors and judicial engineers who were really lawyers.

Identification presents problems and it is one of the difficulties involved in determining requirements for engineers, supply of engineers, or priorities for the use of engineers.

Of course, the amount of formal education possessed by an alleged engineer is always an escape when we know no better way to judge future competence. On perhaps too rare occasions in the absence of evidence of formal education we resort to the examination. This is a device that permits some one who has never done a given kind of work to think up questions that will enable the candidate to demonstrate his ability to do the job that is to be done. We have come a long way in this scientific age in our deference to formal education and to other methods of determining ability to do other than by judging ability to do by doing.

There is always admission as a means of evaluating a human being. This has some limitations as demonstrated by the engineer on the witness stand who testified he was the greatest engineer in the world and when chided for lack of humility he replied that it was not a question of humility or lack of humility, he merely was aware that he was under oath.

The training of an engineer requires effort on the part of the candidate that is not always found among our students. The increase in the tendency toward electives influences many to seek the recognition of the diploma without becoming involved in the work required to learn something about mathematics. A low standard will inevitably result if we insist on bringing all of our students to a single standard.

Admitting that there is a shortage of engineers and that the problem of encouraging suitable young men to study engineering is not easy and that engineering schools are in need of expansion, one would presume that there would be the highest possible utilization of those engineers we do have. There are many indications that is not the case. Has any one estimated the engineer man hours that went into the fine-shaped rear fenders of the nineteen fifty-seven automobiles? How much engineer manpower is engaged continuously in the television industry or the air conditioning industry? The shortage of engineers who are engaged in the task of providing security for the United States will remain so long as we continue to use our engineering brains so lavishly for comforts and entertainment. I doubt seriously that our potential enemies who are said to be outdistancing us in the rate of production of engineers are permitting much engineer brain power to be used on projects that mean so little for the security of their nation.

I do not want to be misunderstood. I dislike regimentation and I am certainly not recommending some form of compulsion in determining where engineers work or for that matter whether they work at all. The facts remain and when we compare our efforts with others the privileges that we protect or over protect are factors. It is an odd commentary that a socialistic state should use capitalistic incentives to get more engineers while a capitalistic state should be depending on methods which might be termed socialistic. In a nation which might be an enemy the carrot is used most extensively to encourage prospects to become engineers and the rewards remain highly satisfactory. There seem to be controls on what they must do and where they must do

it to receive these rewards. Perhaps we can learn something from our competitors even if we have no intentions of adopting their system.

Many of the practices in the acquisition and utilization of engineers in the United States at the present time are not in the long-range best interest of any one. One can but wonder daily, and particularly on Sunday, as to how many of the companies advertising for engineers have contracts with the government and so in the end the taxpayer foots the bill as additional construction costs. How many of the ads are paid for by money which would be otherwise paid in taxes? Could it be that this is one form of advertising a company uses for prestige and other reasons which prompt advertising?

The measures that are taken to procure engineers by high-powered recruiting, by waving before engineering students offers that endow them with feeling of importance that not only make it hard for the college instructor to live with them but arouses his envy as well. Where will it end if each succeeding year the offer to beginners equals or exceeds the amount now paid to last year's crop?

This is no place to discuss methods used to infiltrate other corporations on the chance that some frustrated engineer working there could be coaxed or shall we say bribed to leave.

The use of those who are engineers in many cases is in the area of their least effectiveness rather than their greatest capacity. That may be for the reason that we have not trained sufficient technicians to support the engineers that we have. In a field in which I have only tonight gained standing as I notice from the printed record that I am a Lt. General, Retired, USN, I suppose there could be numbers of admirals high enough to add little to the operation of the Navy if there were no proportionate numbers of lesser officers and sailors.

Specialized manpower confronts our Nation with a serious problem. We need more engineers than we have, we need more and may I suggest better engineering students. We need a lot of hard and serious thinking as to what we do with the engineers we now have. We must decide what things are important enough to use scarce engineer brainpower and what things are so unimportant that we cannot waste engineer brainpower on them.

When we have decided these things we must proceed to educate ourselves and discipline ourselves to do the things best for us all, over the long, not the short pull. It is too much to ask people to be unselfish but if they have the knowledge with which they are generally credited it is not too much to ask them to be intelligent and farseeing in their selfishness.

Government, employers, the engineers, the engineering colleges, and the rest of us must realize that this is a test of the effectiveness of our form of government. Can we inform ourselves fast enough and accurate enough and will our people assume individual responsibility to a degree great enough to insure actions that will increase our chances of survival as a Nation? Can we as citizens muster the confidence in others and so conduct ourselves as to earn confidence in us and by so doing insure unity of action to further the long-range interests of us? If we can, the problem of enough and acceptable engineers will be solved. If we cannot meet this problem, how can we meet the others that will daily threaten our National survival?

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